APPENDIX H
PRELIMINARY RESTORATION STRATEGIES

H.1 INTRODUCTION

The main report and other appendices to the report describe the historical, existing, and desired future conditions of the CFR River (CFR) and Blackfoot River (BFR) near Milltown Dam. The following section details the proposed restoration strategies and techniques that will be employed to move toward the existing condition to the desired future condition. In the context of this section, the term "restoration" refers to the return of the CFR and BFR to conditions similar to their predicted historical condition within the project constraints that are outlined in Section 1.0 of the primary document. The provided definition follows the definition of restoration presented by the EPA (2000), wherein, restoration refers to the return of a degraded ecosystem to a close approximation of its remaining natural potential. Project constraints, numerous anthropogenic-related changes in the restoration project area, and larger system-wide conditions (e.g. noxious weed invasion) make converting the restoration project area to an exact replica of the historical condition impossible. Rather, the proposed restoration plan will emulate what are believed to be a close rendition of the historical conditions while accounting for the project constraints.

Proposed restoration strategies are based on a multi-disciplinary effort that addresses system hydrology, geomorphology, fisheries, botany, and wetlands. Implementing a broad-based interdisciplinary approach to large scale restoration projects is considered essential for restoration project success (Shields et al. 2003). Project engineering is also a critical component of the restoration strategy. Engineering will be employed for developing the site specific restoration plans (Section 4.0 of the main report) necessary for minimizing project risk, for protecting restoration project area infrastructure, and stabilizing contaminated sediments to be left in-place on the CFR floodplain. These constraints do not allow for restoring the CFR to a state of dynamic equilibrium wherein the channel is allowed to meander across its floodplain through erosion and depositional processes. The State determined that allowing for excessive river migration in portions of the restoration project area would not be acceptable. Maintaining vertical and lateral channel stability will be necessary to reduce risks associated with mobilizing contaminated sediments.

The restoration strategies are designed to achieve the restoration objectives established by the State of Montana and the Trustees. Restoration objectives include the following items.

- Restore the CFR and BFR in the Milltown Reservoir Sediment Operable Unit (MRSOU) to be naturally functioning and self-maintaining.
- Use native materials to the extent practical, for stabilizing channels and the floodplain.
- Improve water quality by stabilizing contaminated sediments to be left in place.
- Provide high quality habitat for fish and wildlife.
- Maintain existing infrastructure stability.
- Improve aesthetic values in the area by creating a diverse, natural setting.

- Provide recreational opportunities such as river boating, fishing, and trail access for hiking and bicycling.

This section describes the set of tools that we will use to meet these objectives. Section 3.2 focuses on strategies and techniques for restoring the CFR and BFR channels, the floodplain, and side channels in the restoration project area. Section 3.3 presents strategies and techniques for restoring riparian plant communities and wetlands on the CFR floodplain.

H.2.1 Passive Versus Active Restoration

Restoration techniques may be delineated as either passive or active practices. Passive restoration is defined as changing land management practices and/or allowing the system to recover on its own with no human intervention. Changing land management practices, in particular eliminating activities that result in negative impacts to the ecological processes that are required for the ecosystem to function properly, is necessary to initiate natural ecosystem recovery. Allowing the system to recover with no human intervention may require a longer period of time, but is less costly. Active restoration is defined as physically modifying ecological components where negative changes to ecological and physical processes have reduced the system's ability to recover by itself within an acceptable time frame. While it is important to distinguish between passive and active restoration, most strategies described in the following sections rely on a combination of the two approaches. Due to the dramatic changes that will occur in the MRSOU, the restoration treatments will necessitate active restoration treatments.

H.2 RIVER AND FLOODPLAIN RESTORATION STRATEGIES AND TECHNIQUES

The presented channel design techniques follow the premise of natural channel design whereby the restoration design is based on constructing a channel with appropriate dimensions to convey the sediment and discharge related to the channel-forming discharge. The channel form is affected by independent variables of discharge, sediment supply, and boundary conditions including riparian vegetation and large woody debris. Dependent variables that are a reflection of the watershed and local conditions include the channel cross-section dimensions, channel slope, and channel planform. Determining the appropriate dimensions of the dependent variables is the challenge of the restoration design. Natural channel design is predicated on the concept of restoring the fluvial and biological processes so that the channel will be self-maintaining in the future. The following section introduces the methods that were used in developing the draft restoration design.

H.2.1 Channel Design Methods

Understanding the historical, existing, and potential channel and floodplain conditions and the processes that form those conditions is essential for developing a successful restoration strategy. To maximize the potential for restoration success, we employed three channel design approaches. The approaches include analog, empirical, and analytical techniques (Skidmore et al., 2001).

H.2.1.1 Analog Methods

The analog method includes collecting field data from river reaches displaying stable channel conditions or reference characteristics. Stable reference reaches are surveyed to characterize channel cross-section, planform, and profile dimensions. Examples of best possible conditions may include the following characteristics among other attributes:

- Efficient sediment transport whereby bank erosion and sediment deposition are balanced.
- Riparian vegetation is characterized by dense communities that provide bank stability, contribute woody debris to the channel, and provide riparian and aquatic habitat diversity.
- Channel dimensions are sized to efficiently transport the available sediment load, convey the bankfull discharge, and allow flows exceeding the bankfull discharge to access an adjacent floodplain.
- Maximization of channel length given the valley slope, bed sediment particle size distribution, and riparian vegetation condition (Millar, 2005).

Dimensionless coefficients are developed for the channel dimensions, planform, and profile. Calculated coefficients may be used to compare different surveyed reaches and for developing restoration design dimensions. The dimensionless coefficients are used with average channel features (e.g. average slope, mean riffle depth) to calculate ranges of design dimensions.

The analog is an often used approach due to its simplicity. However, successful application of the method lies in the practitioner's ability to interpret the conditions of the reference reach and the project reach. Misapplying reference reach channel information to the project reach reduces the potential for restoration success.

H.2.1.2 Empirical Methods

Empirical methods are based on professional experience and observation, but are based on larger data sets rather than the local conditions that are evaluated using the analog method (Skidmore et al. 2001). Regime equations and regional hydraulic geometry relationships are used to predict hydraulic properties. A river in regime is considered to be stable and is in dynamic equilibrium with it sediment supply and discharge delivered by the watershed. The river may not necessarily be "locked" into one configuration, but will tend to maintain its average dimensions over a period of time and space as the channel erodes its banks, builds a floodplain, and develops diverse floodplain habitats (Millar, 2000). Regime equations generally relate channel width, depth, and slope to independent variables including bed particle distribution, discharge, or riparian condition (Leopold and Maddock, 1953; Hey and Thorne, 1986; van den Berg, 1995; Millar 2000; 2005). The evolution of regime equation theory continues to be a developing field.

The empirical method's limitations are similar to analog method limitations. The application of empirical methods is generally limited by the availability of large data sets. Similarly, the river data comprising the large data set may vary from the attributes of the project river. Extrapolating regime equation results to an atypical project river may be problematic.

H.2.1.3 Analytical Methods

Analytical approaches, considered to be "process-based" methods of channel design, are based on the premise that channels can be defined by a limited number of independent and dependent variables (Skidmore et al., 2001). Due to the large number of variables (15 as cited in Skidmore et al., 2001), not all of the variables can be feasibly accounted for in formulating restoration designs. To account for this limitation, three groups of equations are used to evaluate sediment transport, bed resistance, and channel continuity. Analytical methods may be used to predict the following variables (Skidmore et al., 2001), 1) sediment load and sediment budget calculations; 2) discharge durations or discharge return intervals; and 3) channel geometry dimensions.

Hydraulic models are used to evaluate channel stability and minimum channel slope that is necessary to convey the expected range of discharge and sediment conditions. Analytical modeling is used to evaluate both existing and design channel conditions. This comparison of existing and proposed channel states is also necessary for evaluating sediment transport continuity through a transitional channel reach.

Analytical method limitations are related to the quality of the data entered into the model and the practitioner's understanding of how the model works. A large number of models have been developed to evaluate sediment transport, flow resistance, and channel stability. These models were developed under unique conditions and should be appropriately selected and applied to the project river. Generally, models are also only effective if field data have been collected to calibrate the modeling results. For example, sediment transport modeling results can vary by two or three orders of magnitude (Barry et al., 2004). Calibrating the model with field data improves model accuracy. Although most analytical modeling programs simplify river complexity, an increasing number of models are able to simulate a river channel in three dimensions and account for bank erosion, vegetation influence, and complex channel hydraulics. These methods typically require a detailed understanding of the models' assumptions, the mathematical basis of the model, and the related appropriateness of the models being used.

Due to theoretical assumptions and limitations that are unique to each of the aforementioned channel design methods, an unacceptable range of answers typically results. Therefore, the standard channel stability assessment involves using a combination of several methods and relying on experience, practicality, and judgment to interpret the results. Finally, applying the analytical methods to the final design dimensions is necessary to ensure that the channel's dimensions, profile, and planform (the dependent variables) are in equilibrium with the discharge, sediment supply, and boundary conditions (the independent variables) characterizing the restoration project area.

H.2.2 Draft Design Criteria

Draft design criteria were developed from the channel design methods. The following sections present the results derived from the channel design methods.

H.2.2.1 Analog Method Results

Reference reach data were collected from several reaches in the CFR and BFR drainages (see Appendix B for complete geomorphic descriptions). To summarize, the reference reaches included:

- ***CFR 3-B*** – A section of the CFR between Turah Bridge and Milltown reservoir. CFR3-B is a single thread channel considered to exhibit most probable state (reference) conditions for a meandering, moderately confined gravel bed channel. Existing condition data were used to formulate design dimensions for the section of the CFR to be reconstructed upstream of the BFR confluence.

- ***Bandmann Reach*** – A section of the CFR from the Interstate 90 bridge (downstream from Milltown Dam), downstream to the confluence of Marshall Creek. The reach was surveyed to characterize channel dimensions in the confined section of the CFR downstream from the confluence. Existing condition data were used to formulate design dimensions for the CFR downstream of the BFR confluence.
- ***Bonner Gage*** – The BFR at the U.S. Geological Survey streamflow gaging station near Bonner (#12340000). The reach was surveyed to estimate the bankfull discharge and channel dimensions through the gaging station. Existing condition data were used to formulate design dimensions for the BFR from the Stimson Dam downstream to the CFR confluence, as well as for the CFR immediately upstream from the confluence.
- ***Ovando Reach*** – The BFR near Ovando, Montana was delineated into three reaches according to degree of channel confinement. Ovando Reach 1 is the upstream section characterized by a moderately confined meandering riffle-pool gravel bed channel morphology. Ovando Reach 2 is a short section characterized by a steeper moderately confined gravel bed riffle-pool channel. Ovando Reach 3 is the downstream section characterized by a bedrock controlled confined riffle-pool gravel bed channel. Reach 1 existing condition data were used to formulate design dimensions for the CFR to be reconstructed upstream from the BFR confluence. Reach 2 existing condition data were used to formulate design dimensions for the BFR from the Stimson Dam downstream to the CFR confluence, as well as for the CFR immediately upstream from the confluence. Reach 3 existing condition data were used to formulate design dimensions for the CFR downstream of the BFR confluence.

Channel cross-section and profile dimensions measured in the field were converted to dimensionless coefficients by dividing bankfull channel values by an appropriate dependent variable. For example, the bankfull pool area was divided by the average riffle area to calculate a dimensionless ratio for pool area. Dimensionless ratios for pool morphology (Table H-1), riffle and run morphology (Table H-2), channel habitat unit slopes (Table H-3), and channel planform geometry (Table H-4) are included below. The cross-section and channel habitat unit data were collected in the field while the channel planform variables were measured from recent aerial photographs.

Table H-1. Dimensionless coefficients for the reference reach pool dimensions stratified by stream type and reach.

	Pool Area/ Riffle Area			Pool Max Depth/ Riffle Mean Depth			Pool Width/ Riffle Width		
Reach	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3 C Reach	1.13	0.86	1.41	2.35	2.29	2.38	1.00	0.93	1.16
Ovando C Reach	0.96	0.79	1.08	2.42	1.94	3.33	0.83	0.72	0.9
Ovando B Reach	1.10			2.60			0.90		
Bonner B Reach									
Ovando F Reach	1.29	1.26	1.33	2.26	2.12	2.41			
Bandmann F Reach	1.50	0.90	2.00	5.20	5.00	5.40	0.72	0.63	0.83

Table H-2. Dimensionless coefficients for reference reach run and riffle dimensions stratified by stream type and reach.

	Run Max Depth/ Riffle Mean Depth			Riffle Max Depth/ Riffle Mean Depth			Run Width/ Riffle Width		
Reach	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3 C Reach	2.42	2.4	2.45	2.42	2.4	2.45	2.42	2.4	2.45
Ovando C Reach	1.75	1.34	2.29	1.75	1.34	2.29	1.75	1.34	2.29
Ovando B Reach	1.76	1.42	2.10	1.76	1.42	2.10	1.76	1.42	2.10
Bonner B Reach									
Ovando F Reach	1.65			1.65			1.65		
Bandmann F Reach	1.90	1.80	1.99	1.90	1.80	1.99	1.90	1.80	1.99

Table H-3. Dimensionless coefficients for the reference reach channel habitat unit slopes stratified by stream type and reach.

	Pool Slope/ Average Slope			Riffle Slope/ Average Slope			Run Slope/ Average Slope			Pool to Pool Spacing/ Riffle Width		
Reach	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3 C Reach	0.20	0.12	0.24	2.34	1.19	3.77	0.50	0.25	0.76	3.76		
Ovando C Reach	0.35	0.00	0.85	1.53	0.41	5.22	0.80	0.00	2.97	5.26	1.29	19.90
Ovando B Reach	0.33			2.15	1.14	4.42	0.86	0.58	1.02	10.80		
Bonner B Reach				1.70	0.51	2.42	0.70	0.52	0.91			
Ovando F Reach	0.23	0.03	0.44	0.98	0.46	1.38	0.71	0.50	0.98	11.96		
Bandmann F Reach	0.00	0.00	0.05	1.36	1.05	1.82	3.37	0.21	5.92			

Table H-4. Dimensionless coefficients for the reference reach planform geometry stratified by stream type and reach.

	Meander Length/ Riffle Width			Radius of Curvature/ Riffle Width			Beltwidth / Riffle Width		
Reach	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3 C Reach	9.60	8.25	10.93	2.40	2.22	2.56	3.80	3.41	4.10
Ovando C Reach	10.20	5.38	15.40	2.57	0.88	4.08	4.70	2.91	7.64
Ovando B Reach	N/A			N/A			2.00	1.39	2.70
Bonner B Reach	N/A			N/A			2.60		
Ovando F Reach	11.20	8.45	13.79	3.70	2.55	4.77	2.86	2.81	2.89
Bandmann F Reach	19.20			8.37			6.30		

The dimensionless coefficients were then used to develop draft channel dimensions for the restoration project area. Conversion from the dimensionless coefficients to channel area and distances was completed by multiplying the coefficients by the appropriate channel variable. For example, pool area was determined as the product of the pool area dimensionless coefficient presented in Table H-1 multiplied by the design riffle area. Pool design dimensions (Table H-5), riffle and run design dimensions (Table H-6), channel habitat unit slopes (Table H-7), and channel planform dimensions (Table H-8 and Table H-9) are included below.

Table H-5. Calculated pool dimensions for the restoration project reaches. Dimensionless coefficients provided in Table H-1 were multiplied by design riffle dimensions to derive pool dimensions.

	Riffle Area	Riffle Depth	Riffle Width	Pool Area (ft^2)			Pool Max Depth (ft)			Pool Width (ft)		
Reach (Source Coeffs)	(ft^2)	(ft)	(ft)	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C (CFR3)	550	3.7	148	622	473	776	8.7	8.5	8.8	148	138	172
CFR3/CFR2 C (Ovando C)	550	3.7	148	528	435	594	9.0	7.2	12.3	123	107	133
CFR2 B (Ovando B)	530	3.6	146	583			9.4			131		
CFR2 B (Bonner B)												
BFR1 (Ovando F)	960	4.9	196	1238	1210	1277	11.1	10.4	11.8			
BFR1 (Bandmann F)	960	4.9	196	1440	864	1920	25.5	24.5	26.5	141	123	163
CFR1 (Ovando F)	1480	6.1	243	1909	1865	1968	13.8	12.9	14.7			
CFR1 (Bandmann F)	1480	6.1	243	2220	1332	2960	31.7	30.5	32.9	175	153	202

Table H-6. Calculated run and riffle dimensions for the restoration project reaches. Dimensionless coefficients provided in Table H-2 were multiplied by design riffle dimensions to derive the run and riffle max depth

	Riffle Area	Riffle Depth	Riffle Width	Run Max Depth (ft^2)			Run Width (ft)			Riffle Max Depth (ft)		
Reach (Source Coeffs)	(ft^2)	(ft)	(ft)	Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C (CFR3)	550	3.7	148	9.0	8.9	9.1	129	121	135	5.6	4.5	7.2
CFR3/CFR2 C (Ovando C)	550	3.7	148	6.5	5.0	8.5	135	117	152	5.2	4.5	5.7
CFR2 B (Ovando B)	530	3.6	146	6.3	5.1	7.6	117	117	123	5.1	4.5	5.9
CFR2 B (Bonner B)												
BFR1 (Ovando F)	960	4.9	196	8.1			186			7.8	6.4	9.2
BFR1 (Bandmann F)	960	4.9	196	9.3	8.8	9.8	153	151	155	7.0	6.6	7.3
CFR1 (Ovando F)	1480	6.1	243	10.1			231			9.7	8.0	11.5
CFR1 (Bandmann F)	1480	6.1	243	11.6	11.0	12.1	190	187	192	8.7	8.2	9.0

Table H-7. Calculated habitat feature slopes for the restoration project reaches. Dimensionless coefficients provided in Table H-3 were multiplied by average slope to derive the habitat feature slopes.

Reach (Source Coeffs)	Ave Slope	Pool Slope			Riffle Slope			Run Slope		
		Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C (CFR3)	0.0027	0.0005	0.0003	0.0006	0.0063	0.0032	0.0102	0.0014	0.0007	0.0021
CFR3/CFR2 C (Ovando C)	0.0027	0.0009	0.0000	0.0023	0.0041	0.0011	0.0141	0.0022	0.0000	0.0080
CFR2 B (Ovando B)	0.0036	0.0012	0.0000	0.0000	0.0077	0.0041	0.0159	0.0031	0.0021	0.0037
CFR2 B (Bonner B)	0.0036				0.0061	0.0018	0.0087	0.0025	0.0019	0.0033
BFR1 (Ovando F)	0.0030	0.0007	0.0001	0.0013	0.0029	0.0014	0.0041	0.0021	0.0015	0.0029
BFR1 (Bandmann F)	0.0030	0.0000	0.0000	0.0002	0.0041	0.0032	0.0055	0.0101	0.0006	0.0178
CFR1 (Ovando F)	0.0031	0.0007	0.0001	0.0014	0.0030	0.0014	0.0043	0.0022	0.0016	0.0030
CFR1 (Bandmann F)	0.0031	0.0000	0.0000	0.0002	0.0042	0.0033	0.0056	0.0104	0.0007	0.0184

Table H-8. Calculated planform dimensions for the restoration project reaches. Dimensionless coefficients provided in Table H-4 were multiplied by design riffle dimensions to derive the planform dimensions.

Reach (Source Coeffs)	Bankfull Width (ft)	Meander Length (ft)			Radius of Curvature (ft)			Beltwidth (ft)		
		Ave	Min	Max	Ave	Min	Max	Ave	Min	Max
CFR3/CFR2 C Reach (CFR3)	148	1,421	1,221	1,618	355	329	379	562	505	607
CFR3/CFR2 C Reach (Ovando C)	148	1,510	796	2,279	380	130	604	696	431	1,131
CFR2 B (Ovando B)	146	1,343	1,237	1,435	1,475	1,381	1,580	292	203	394
CFR2 B (Bonner B)	146	1,825			803			380		
BFR1 (Ovando F)	196	2,195	1,656	2,703	725	500	935	561	551	566
BFR1 (Bandmann F)	196	3,763			1,641			1,235		
CFR1 (Ovando F)	243	2,722	2,053	3,351	899	620	1,159	695	683	702
CFR1 (Bandmann F)	243	4,666			2,034			1,531		

Table H-9. Calculated pool to pool spacing for the project reaches. Spacing is the product of the riffle width and the dimensionless coefficients included in Table H-3.

Reach (Source Coeffs)	Bankfull Width (ft)	Pool to Pool Spacing (ft) Ave	Min	Max
CFR3/CFR2 C (CFR3)	148	556		
CFR3/CFR2 C (Ovando C)	148	778	191	2945
CFR2 B (Ovando B)	146	1577		
CFR2 B (Bonner B)	146			
BFR1 (Ovando F)	196	2344		
BFR1 (Bandmann F)	196			
CFR1 (Ovando F)	243	2906		
CFR1 (Bandmann F)	243			

The analog results provide a range of channel cross-section, profile, and planform dimensions for the restoration project area. The reference reach results offer in some cases a wide range of potential channel dimensions that were evaluated along with the empirical and analytical results. Additional discussion of the reference reach design dimensions is included below in the context of the results derived from the other methods.

H.2.2.2 Empirical Method Results

Theoretical regime equations were evaluated as a method for developing design channel dimensions as well as testing the argument of whether the CFR upstream from Milltown reservoir historically displayed a single thread or braided channel planform. The following analysis includes optimality regime equations presented by Millar (2005); meandering-braiding threshold equations provided by Millar (2000; 2005) and van den Berg (1995), Three regime equations were used to develop design channel cross-section and planform dimensions. The first equation provided by Millar (2005) predicts channel morphology based on optimality theory.

Millar Regime Equations

Optimality theory is based on the idea that a channel in dynamic equilibrium can migrate across its floodplain while maintaining its average channel dimensions and slope as long as the discharge, bedload inputs, and bank strength remain consistent (Mackin, 1948; Lane, 1955; Millar 2005). Applying the optimality theory regime equations requires data inputs for bankfull discharge, channel slope, and the ratio of critical bank shear stress to critical shear stress. Millar's equations incorporate streambank vegetation density as an influential variable related to bank strength. This approach is an innovation over previous regime equations that did not account for riparian vegetation influence. Once calibrated with data for independent variables included in the model, the equations adequately describe hydraulic geometry and provide strong support for an optimal state for equilibrium channel conditions. Modeling results may be calibrated by solving for channel width-to-depth ratios and comparing the results to actual channel conditions measured in the field.

Methods
The three regime equations presented in Millar (2005) and used in our analysis are summarized below. For a more detailed discussion of the theoretical underpinnings of the equations, the reader is referred to Millar (2005) and the references included therein. The foundation of the regime equations we applied are based on the following dimensionless independent variables for discharge, sediment concentration, and relative bank strength (Millar, 2005).

Our analysis was limited to alluvial reaches of the CFR (CFR3-B and CFR3-A) and the BFR (Ovando Reach 1). The other surveyed reaches were deemed to be laterally controlled by bedrock, hillslopes, and terraces. These features functioned as the primary controls on channel geometry, and so conflict with the model's assumptions.

$Q^*=Q/(d_{50}^2\sqrt{gd_{50}(s\text{-}1)})$ where Q represents the bankfull discharge (m^3/s), g represents gravitational acceleration (9.8 m/s^2), d_{50} is the median bed particle diameter (m), s is the specific sediment weight (2.65).

$C^* = -\log_{10}C$ where C is the dimensional sediment concentration.

$\mu' = \tau_{banks}/\tau_{bed}$ where τ_{banks} and τ_{bed} refers to the dimensional critical shear stresses (Pa) for the bank and bed sediments, respectively. This relationship is an indicator of streambank strength and accounts for the influence of vegetation and bank material size on streambank angle. Higher μ'-values represent greater bank strength afforded by riparian vegetation. A μ'-value of 1.5 would suggest that densely vegetated rivers have banks that are on average up to 1.5 times more resistant to scour than the channel bed (Millar, 2005).

The following theoretical regime equations are derived from the aforementioned dimensionless independent variables. The W^* and D^* results are corrected for the d_{50} particle size according to $W^* = W/\ d_{50}$ and $D^* = D^*/\ d_{50}$.

$$W^* = 28.1Q^{*0.50}\ C^{*-1.12}\mu'^{-1.66}$$

$$D^* = 0.0764Q^{*0.37}\ C^{*1.16}\mu'^{1.22}$$

$$S = 1.98\ Q^{*-0.33}\ C^{*-1.86}\mu'^{-0.93}$$

$$W/D = 425Q^{*0.12}\ C^{*-2.30}\mu'^{-2.90}$$

The theoretical regime equations suggest the dependence of hydraulic geometry variables on bankfull discharge, bedload, and bank strength. Because C^* is difficult to calculate since it is based on sediment concentration data derived from bedload samples, S (reach-averaged channel gradient presumed to be representative of the energy slope) is substituted for C^* as an independent indicator of stream power. The following equations result from substituting S for C^*.

$$W^* = 16.5Q^{*0.70}S^{0.060}\mu'^{-1.10}$$

$$D^* = 0.125Q^{*0.16}S^{-0.62}\mu'^{0.64}$$

$$W/D = 155Q^{*0.53}S^{1.23}\mu'^{-1.74}$$

We applied the reach-specific values for Q, S, d_{50} for each of the reference reaches listed above as well as for a braided section of the CFR upstream of the CFR3-B reference reach. Values for μ' were not calculated for each reach, but rather, a range of μ'-values were used. Values for μ' ranged from 1 (poor vegetation condition, banks and bed equally erodible) to 1.7 (dense vegetation condition, banks 1.7 times more erosion resistant than bed).

Results

Modeling results were compared to field data collected on the alluvial reference reaches. Comparing the regime equation results to actual channel conditions, the regime equations predicted narrower and deeper channels than the reach-averaged channel conditions in each of the survey sections. Only the regime equation results for the CFR3-B reference reach were found to be similar to the actual channel dimensions measured in the field (Table H-10). However, the predicted channel dimensions that were in accordance with the actual channel dimensions were calculated using μ'-values of 1.1. The 1.1 value for μ' represents semi-unvegetated banks or lower bank strength according to the regime equation parameters. These results would suggest that the banks would be on average 1.1 times more resistant to scour than the channel bed, or roughly equally resistant to fluvial entrainment. Contrasting with the expected channel conditions that would be related to a bank condition that is susceptible to erosion, the CFR3-B reference reach's planform has remained consistent over time as determined from the aerial photo time series analysis (plate 5, 1937 vs 2000), suggesting that the stream banks are relatively resistant to fluvial scour.

Table H-10. Optimality theory regime equations completed for the CFR in CFR3-B (C4 stream type). Modeling results are compared to the average channel dimensions measured in the field (**Bold**). μ'-values represent increasing levels of bank vegetation density.

	Modeling Results			
μ'	Width (ft)	Depth (ft)	W/D	Notes
1.0	195.8	3.18	60.6	No vegetation
1.1	176.3	3.38	51.3	
1.3	146.7	3.76	38.4	Intermediary vegetation
1.5	125.3	4.12	29.9	
1.7	109.2	4.46	24.1	Max vegetation
Ref	**172**	**3.47**	**49.6**	**All types mean**
Ref	**172**	**6.14**	**28**	**All types max**

Prediction results for Ovando Reach 1 similarly underestimated the actual channel dimensions measured in the field (Table H-11).

Table H-11. Optimality theory regime equations completed for the BFR near Ovando, Reach 1 (C4 stream type). Modeling results are compared to the average channel dimensions measured in the field (**Bold**). μ'-values represent increasing levels of bank vegetation density.

	Modeling Results			
μ'	Width (ft)	Depth (ft)	W/D	Notes
1.0	126.1	4.9	25.7	No vegetation
1.1	113.6	5.2	21.7	
1.3	94.5	5.8	16.2	Intermediary vegetation
1.5	80.7	6.3	12.7	
1.7	70.4	6.9	10.2	Max vegetation
Ref	**160**	**3.4**	**47.1**	**All types mean**
Ref	**160**	**5.65**	**28.3**	**All types max**

The final regime equations run was completed for a braided section of the CFR downstream from Turah Bridge (Table H-12). Channel braiding in the reach is attributed to land management practices, confinement of the valley bottom by infrastructure, and elevated sediment contributions to the channel related to upstream inputs and local bank erosion.

Table H-12. Optimality theory regime equations completed for the CFR in CFR3-A (braided D4 stream type). Modeling results are compared to the average channel dimensions measured in the field (**Bold**). μ'-values represent increasing levels of bank vegetation density.

	Modeling Results			
μ'	Width (ft)	Depth (ft)	W/D	Notes
1.0	152.6	3.70	41.4	No vegetation
1.1	137.4	3.93	35.1	
1.3	114.4	4.37	26.2	Intermediary vegetation
1.5	97.7	4.79	20.4	
1.7	85.1	5.19	16.4	Max vegetation
Ref	**708**	**1.71**	**414**	**All types mean**
Ref	**708**	**6.38**	**111**	**All types max**

Summary

Overall, the optimality theory regime equations under-predicted the channel widths and over-predicted the channel depths, although the channel depth relationships varied. Predicted width-to-depth ratios were typically substantially lower than the actual field-measured width-to-depth ratios. Millar concluded the analysis of the regime equations by noting that for a particular discharge, a wide range of optimal channel widths is possible is possible and that from a restoration perspective designing the appropriate channel slope is the most critical component for maintaining channel stability. If the minimum channel slope requirement is met, then a range of near-optimal channel widths could be designed and the channel would remain stable.

Several reasons explain the differences between the predicted channel dimensions and the actual field measurements. First, as highlighted in the discussion of empirical equation limitations, the data bases that were used to develop the regime equations may have included rivers formed by processes that vary from conditions defining the CFR and BFR. Secondly, the regime equations were based on average conditions and did not differentiate between habitat features. We found substantial variability in habitat units (i.e. riffles, runs, pools). The predicted channel dimensions

appeared to better predict pool widths and riffle depths, providing a range of predicted channel dimensions. Better stratifying the base data set could produce regime equations that more accurately define habitat unit dimensions.

To conclude, the results from the optimality theory regime equations point to the importance of riparian vegetation in maintaining bank integrity and channel stability. Theoretical increases in the bank vegetation density had a substantial affect on the predicted channel widths. Perhaps the difference in the actual channel conditions and the regime equation predictions is due to the surveyed reaches not functioning at an optimal level. The optimality theory predictions will be included with the results from the other channel design methods to provide an overall range of potential design channel conditions (see Appendix C and the Appendix H summary).

Meandering Versus Braiding Channel Threshold Regime Equations

The historical condition of the CFR in the vicinity of Milltown reservoir has been a topic of discussion and a point of disagreement in the *Draft Conceptual Restoration Plan* (Water Consulting, Inc. and Wildland Hydrology, 2003). Early maps depicting the reach offer conflicting interpretations of the channel planform morphology of the CFR upstream of the BFR confluence. While several maps from the late 1800s and early 1900s characterized the river with a mulit-channel planform, other historical maps illustrated the river as a single meandering channel. Maps and aerial photographs completed in the early part of the 1900s are believed to have captured a river already exhibiting the effects of 50 years of extractive land uses throughout the watershed and do not accurately reflect the historical (pre-European American influence) conditions of the river corridor.

Definitions for meandering and braided channel conditions are well defined in the literature. These two conditions represent end points in a channel continuum that includes an intermediate condition referred to as anastomosing, anabranching, or wandering channels. Meandering channels are considered to be sinuous single-thread channels, although straight channels (sinuosity <1.5) are also included in this category (Leopold and Wolman, 1957; Van den Berg, 1995; Millar, 2000). The term braided refers to wide and typically shallow channels that at low flows generally have exposed unvegetated bars and islands. As discharge nears the bankfull flow, the bars are submerged and reworked (Millar, 2000). Anastomosing, anabranching, wandering, and multi-thread channels are characterized by multiple channels separated by stable, vegetated islands that remain emergent at or near bankfull discharge (Nanson and Knighton, 1996; Millar, 2000; Tooth and Nanson, 2004). The wandering channel type is considered intermediate to meandering and braided channel types. The continuum of channels represents a trend of increasing flow energy.

The meandering-braiding channel threshold has been a topic of interest for over forty years dating to work done by Leopold and Wolman (1957) and Lane (1957). More recent work by Van den Berg (1995), Millar (2000; 2005), Nanson and Knighton (1996), and Tooth and Nanson (2004) expand model complexity in attempting to identify the variables that most accurately differentiate among straight, meandering, braided, and wandering channel planforms. Several of these equations were applied in an attempt to address the question of historical channel planform for the CFR.

The following analysis presents three methods that were employed to clarify the potential historical condition of the CFR. The three methods present a range of techniques that incorporate different independent variables to define channel planform.

Methods

Leopold and Wolman (1957): The equation provided by Leopold and Wolman (1957) was based on a wide range of natural channels throughout the world. The meandering-braided threshold equation was derived by comparing bankfull discharge (ft^3/s) and channel slope. Leopold and Wolman considered braided channels to be "those reaches in which there are relatively stable alluvial islands, and hence two or more separate channels" (1957). This definition is more similar to the contemporary definition of an anastomosed or wandering channel rather than a braided channel. Leopold and Wolman premise this equation with the caveat that the included data were not segregated by channel material and focuses only on two variables, missing complex processes (e.g. riparian vegetation influence) that could affect channel planform. The Leopold and Wolman equation follows.

$s = 0.06Q^{-0.44}$ where s is the channel slope and Q is the bankfull discharge (cfs).

Millar (2000; 2005): Millar developed an empirical model to evaluate streambank vegetation influence on bank strength. The model tests the hypothesis that the bank sediment and riparian vegetation are the dominant variables influencing streambank erodability, and thus, affects channel slope. Millar surmised that S^* (meandering-braiding transition slope) is proportional to the relative strength of streambanks. Streambank strength could be created either by vegetation, bank sediment, or other stabilizing features. As bank strength increases, steeper channel slopes would be necessary to cause channel braiding via lateral bank erosion and sediment delivery. Therefore, bank erosion resistance influences alluvial channel planform development.

According to Millar (2000), bank sediment friction angle (Φ'), is used as a surrogate for the density of riparian vegetation. The friction angle is a parameter for different processes including the reduction of near-bank flow velocity and shear stress, bank strength provided by root networks, streambank materials, and bank material packing and cementing (Millar, 2000). The friction angle summarizes these processes into one parameter. Bank angles of 90 degrees indicate lush riparian vegetation with maximum bank strength. Bank angles of 40 degrees correspond to minimal riparian vegetation, high erodability, and negligible bank strength.

The purpose of the analysis was to establish a meandering-braided transition slope that would discriminate between meandering and braided rivers based on bank strength related to vegetation condition. Channel slopes above the meandering-braided transition slope would be expected to maintain a braided planform, while channel slopes below the line would be expected to maintain a meandering channel pattern. The equation is as follows.

$S^* = 0.0002 * d_{50}^{0.61} * \Phi'^{\,1.75} * Q^{-0.25}$ where S^* is the meandering-braided transition slope, d_{50} is the composite median particle size (m), Φ' is the bank sediment friction angle in degrees, and Q is the bankfull discharge (m^3/s).

We processed the equation with a range of Φ'-values to represent bank conditions varying from a low angle of repose ($\Phi' = 40°$) to a near-vertical bank profile ($\Phi' = 80°$). As the theoretical bank angle approaches 90 degrees, the optimal channel cross-section would be expected to become narrower and deeper with a lower width-to-depth ratio. In addition to testing the theoretical Φ'-values, we also tested field-measured bank angles from CFR3. The d_{50} values were taken from composite sediment data collected in CFR3. The bankfull discharge was derived from field surveys and flood frequency analysis.

Millar (2005) reanalyzed the above equation using dimensionless variables (following methods covered in the *Millar Regime Equations* section above). The revised equation with dimensionless variables is as follows.

$S^* = 0.0957{*}Q^{-0.25}\mu'$ where S^* is the meandering-braided transition slope, Q is the bankfull discharge (m^3/s), and μ' is an indicator of bank strength based on riparian vegetation density.

Results

Leopold and Wolman (1957): The existing channel conditions for the CFR upstream from Milltown Reservoir exhibit conditions on the threshold of meandering and braided according to the Leopold and Wolman (1957) graph (Figure H-1). The design dimensions for CFR2 and CFR3 likewise plot above the meandering-braided threshold and would suggest a braided channel planform is appropriate for the CFR upstream of the reservoir. However, one critical element of the river channel patterns that Leopold and Wolman discuss is the occurrence of straight channels (undivided channels with sinuosity <1.5) (Leopold and Wolman, 1957; Tooth and Nanson, 2004). Straight channels are located on either side of meandering-braided threshold line. The results of the historical and contemporary channel planform analysis completed on the CFR suggested that channel sinuosity has not exceeded 1.33 at least over the past 70+ years (see Appendix D). The existing channel sinuosity upstream of Milltown reservoir is 1.14, whereas the draft design sinuosity for CFR3 and CFR2 are 1.25 and 1.17, respectively. Therefore, it is not unreasonable to expect the existing channel conditions as well as the draft design dimensions to fall above the meandering-braided threshold line considering that the CFR in this area would be classified as a straight channel according to the Leopold and Wolman analysis. Additionally, the two variables that are used to derive the meandering-braided threshold only incorporate two variables. Incorporating more variables such as the d_{50} particle size (Ferguson, 1987) or bank vegetation condition (Millar, 2000), or stream power (Van den Berg, 1995; Bledsoe and Watson, 2001), could provide a more refined predictor of the meandering-braiding transition slope.

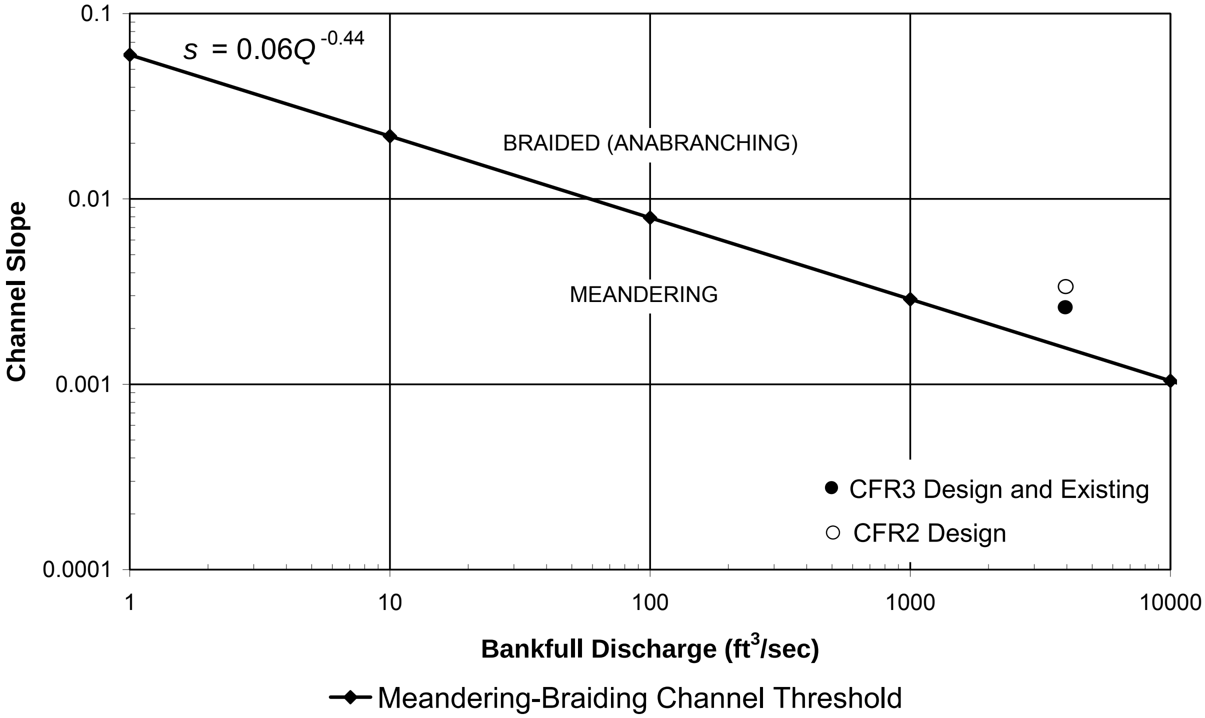

Figure H-1. The slope vs. discharge diagram with solid line discriminating between meandering and braided channels as determined by Leopold and Wolman (1957). The CFR3 design and existing, and the CFR2 design fall in the braided area of the curve. However, the low channel sinuosity classifies the reaches as straight channels. Leopold and Wolman found that straight channels exist in both the meandering and braided portions of the channel continuum.

Millar (2000; 2005)*:* Values for bankfull discharge, d_{50}, and a range of Φ'-values spanning from 40 degrees to 90 degrees were used for the model. The resulting transition slope (S*) was compared to the actual channel slope to predict the channel planform. We then compared the predicted channel planform to the observed planform. Modeling results predict that the CFR should be a meandering river based on the predicted transition slopes exceeding the observed channel slopes. These results accurately predict Reach CFR3-B (Table H-13), but poorly predict the actual braided channel planform of CFR3-A (Table H-14) and CFR3-C (Table H-15). This discrepancy may be due to CFR3-A and CFR3-C exhibiting the effects of watershed disturbance that has directly altered channel planform and gradient, increased sediment loading, reduced native vegetation density, and confined the valley bottom. These reaches now appear to function more as wandering channels with stable islands rather than a braided channel condition. Millar stated that the transitional slope predictions are robust for differentiating between meandering and braided channel planforms, but are less reliable for predicting a wandering channel planform. This could be one reason why the multiple channel planform in CFR3-A and CFR3-C were not accurately predicted by the model.

Other reasons for not correctly predicting the braided reaches could be due to differences between the bank and bed materials. The model assumes similar bed and bank materials and does not account for differences if they do exist. Bank materials in CFR3-C tend to be finer (floodplain deposition due to Milltown Dam backwater effect) than the bed and would be expected to be more susceptible to scour. This would result in lower bank strength even as bank

angle approaches 90 degrees. Millar refers to other more flexible equations that could be used to account for bed and bank material variation.

Table H-13. Channel variables measured in the CFR3-B reference reach. Theoretical Φ'-values from Millar (2000). Existing channel slope (S) compared to meandering-braided transition slope (S*). S < S* result predicts a meandering channel planform. M represents meandering; B represents braided.

Reach	d_{50} (m)	Φ' (degrees)	Q (cms)	S	S*	Predicted	Observed
Theoretical Φ'	0.03	40	98	0.0028	0.0048	M	M
	0.03	60	98	0.0028	0.0097	M	M
	0.03	80	98	0.0028	0.0160	M	M
	0.03	40	98	0.003	0.0048	M	M
	0.03	60	98	0.003	0.0097	M	M
	0.03	80	98	0.003	0.0160	M	M
Measured Φ'	0.03	82	98	0.0028	0.0167	M	M

Table H-14. Channel variables measured in the CFR3-A reach. Theoretical Φ'-values from Millar (2000). Existing channel slope (S) compared to meandering-braided transition slope (S*). S < S* result predicts a meandering channel planform. M represents meandering; B represents braided.

Reach	d_{50} (m)	Φ' (degrees)	Q (cms)	S	S*	Predicted	Observed
Theoretical Φ'	0.056	40	98	0.0039	0.007	M	B
	0.056	60	98	0.0039	0.014	M	B
	0.056	80	98	0.0039	0.023	M	B
	0.056	40	98	0.0028	0.007	M	B
	0.056	60	98	0.0028	0.014	M	B
	0.056	80	98	0.0028	0.023	M	B
Measured Φ'	0.056	50	98	0.0039	0.010	M	B

Table H-15. Channel variables measured in the CFR3-C reach. Theoretical Φ'-values from Millar (2000). Existing channel slope (S) compared to meandering-braided transition slope (S*). S < S* result predicts a meandering channel planform. M represents meandering; B represents braided.

Reach	d_{50} (m)	Φ' (degrees)	Q (cms)	S	S*	Predicted	Observed
Theoretical Φ'	0.0177	40	98	0.0027	0.003	M	B
	0.0177	60	98	0.0027	0.007	M	B
	0.0177	80	98	0.0027	0.012	M	B
Measured Φ'	0.0177	86.25	98	0.0027	0.013	M	B

Based on the CFR results, the river in Reach 3 is best predicted as either a meandering or wandering channel. The predicted transition slope-observed channel slope pairs are plotted in Millar's channel continuum graph (Figure H-2). The calculated pairs plot below the meandering-braided transition line and are located adjacent to both meandering and wandering channel types.

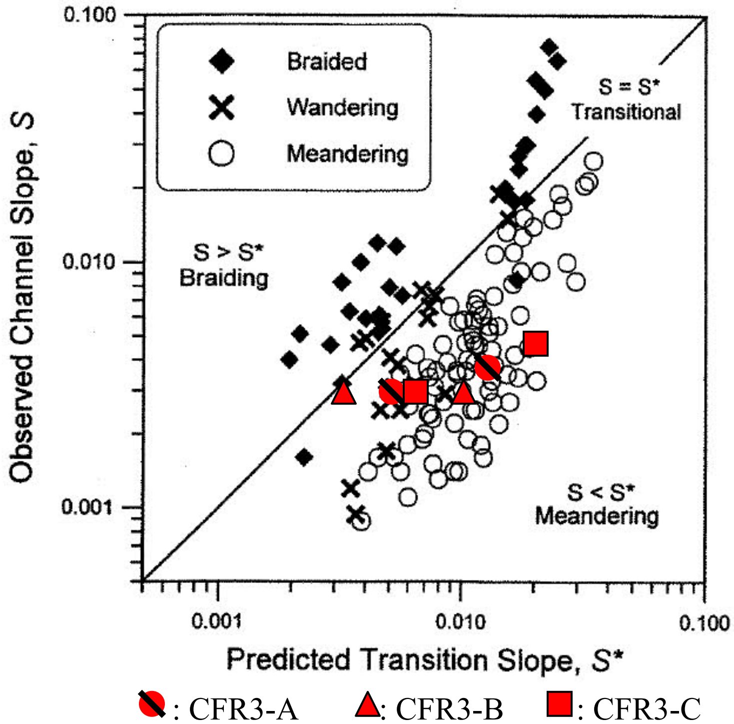

Figure H-2. Comparison of the observed channel slope (S) and predicted transition slope (S*) calculated for CFR3-A, 3-B, and 3-C. The respective symbols are placed at the upper and lower limits of the slope pair values for each of the three reaches. All slope pairs plotted below the meandering-braided transition line, predicting meandering channels. The slope pairs also plotted near wandering channel data points plotted by Millar (2000), potentially predicting a wandering channel planform. The graph was taken from Millar (2000).

The meandering-braided transition slope using Millar's dimensionless meandering-braiding criterion (2005) was also evaluated. The equation replaces the d_{50} and bank angle variables in the 2000 equation with μ', a surrogate parameter for bank strength based on streambank vegetation density. The model compares the observed channel slope to the meandering-braiding transition slope (*S**) (Figure H-3). The model is limited to channels that are stable over time and are neither aggrading or degrading. Due to this constraint, we only evaluated CFR3-B since it appears to have maintained consistent conditions since 1937 (aerial photograph analysis). Conversely, CFR3-A and CFR3-C are currently experiencing aggradation and have changed substantially over time.

The model predicted a meandering planform based on the discharge and μ'-values that ranged from 1.0 (poor bank vegetation) to 1.7 (very dense bank vegetation) (Table H-16). The slope pairs fell within the scatter of meandering channels provided by Millar (2005) and had similar values to data analyzed by Hey and Thorne (1986, *cited in* Millar, 2005). The results suggest that a meandering channel would be expected based on the observed channel slope and the bankfull discharge despite having a poor streambank vegetation condition. Since the historical and draft design average channel slopes for CFR3 are within the range of 0.0027 to 0.0036, a single meandering channel would be expected according to this model.

Table H-16. Dimensionless meandering-braiding criterion for CFR3-B. Observed channel slope (S) and the meandering-braiding transition slope (S*) are presented. Two channel slopes were measured in CFR3-B. The predicted and observed channel patterns are denoted as meandering (M).

Reach	μ'	Q (cms)	S	$S*$	Predicted	Observed
CFR3-B	1.0	98	0.0039	0.0304	M	M
	1.7	98	0.0039	0.0517	M	M
	1.0	98	0.0028	0.0304	M	M
	1.7	98	0.0028	0.0517	M	M

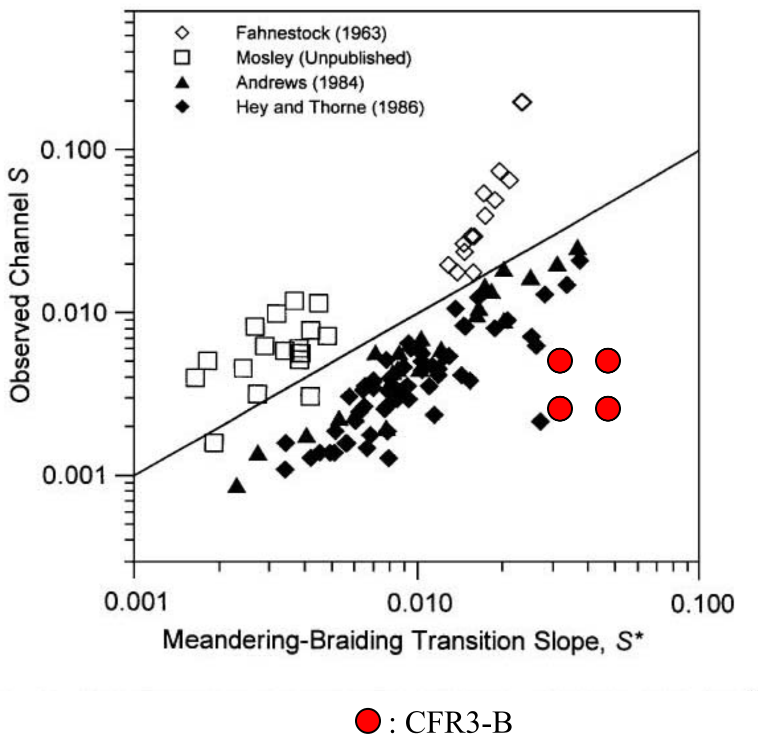

Figure H-3. Comparison of the observed channel slope (S) and predicted meandering-braided transition slope (S*) calculated for CFR3-B. The symbols represent the minimum and maximum possible results based on poor (μ' = 1.0) and dense bank vegetation (μ' = 1.7) and the two observed channel slopes in the reach. Denser bank vegetation would be correlated with increased bank strength. A steeper channel slope would be required to cause braiding when bank vegetation is dense. The graph was taken from Millar (2005).

Regime equations offer another tool in predicting channel planform. Three models were evaluated for predicting channel planform based on channel and valley slope, median particle size, bank angle, and vegetation condition. The regime equations provide a simplified means for evaluating channel planform. The variables in the models are generally surrogates for more complex processes. For example, bank angle in Millar's equation is an indicator of bank strength that could be related to bed material size and composition, and vegetation condition. Although these surrogate indicators make the models more simple, they also make the models more rigid. For instance, differences in bank and bed material particle sizes is not accounted for

in Millar's equation, an issue that could be critical for evaluating bank stability and scour potential. Although evaluating more regime equation models would be one approach to further investigating the issue of historical channel planform on the CFR, the regime equations should be used as one of many tools in evaluating historical, existing, and potential channel conditions. For the regime equations we completed, the models predicted either a straight (Leopold and Wolman method) or meandering channel (Millar) planform for the CFR upstream from Milltown reservoir.

H.2.2.3 Analytical Method Results

The following section includes summary modeling results for the analytical methods that we employed to evaluate the existing reaches and the proposed channel dimensions. Proposed channel dimensions were generally derived from analog, empirical, and analytical modeling results. For a more detailed description of the analytical methods and results, see Appendix C.

Stable Slope Analysis

Methods for estimating stable channel slope predict slopes that correspond to a threshold hydraulic condition for the initiation of movement for a specific bed material size class. As such, available equations rely on input data for bed composition, mean depth and dominant discharge. Results indicate that observed average slopes are less than estimated stable slopes for nearly all methods and all reaches (Table H-17). Since the selected reference reaches are stable and do not appear to be aggrading, it can be concluded that a range of acceptable slopes is available for the proposed design reaches. Most selected design slopes are within the acceptable range for stable slope. For those values less than the acceptable range, it may be necessary to adjust other hydraulic variables such as width-depth ratio so that the proposed channel does not experience aggradation. For those values greater than the acceptable range, it may be necessary to increase the frequency of grade control structures or increase the width-depth ratio.

Table H-17. Comparison of estimated stable slope and average slope (ft/ft) for selected reference reaches and proposed project reaches.

Critical Slope Method	CFR3 Middle C4	CFR1 Bandmann F3/1	BFR1 Bonner B3	BFR Ovando C4	BFR Ovando B3	BFR Ovando F4
Actual Average Slope	0.00281	0.00193	0.00321	0.00236	0.00246	0.00235
Selected Design Slope	0.0031 - 0.0043	0.0030 - 0.0032	0.0025 - 0.0040	N/A	N/A	N/A

Bed Resistance and Channel Velocity Analysis

Channel velocity is a function of channel slope, channel geometry, and channel roughness. Available methods for estimating critical velocity predict mean velocities that correspond to a threshold hydraulic condition for the initiation of movement for a specific bed material size class. As such, available equations rely on input data for bed composition, mean depth and slope. Summary results are included in Table H-18.

Channel roughness was used to estimate critical velocities in order to validate proposed channel velocities and compute proposed channel cross-sectional area. For this analysis, it was assumed that available bed material in the restoration project area will resemble that found in the corresponding reference reaches. As with other models, these equations have limitations of applicability. Many have been developed for the purpose of designing armored flood control channels. Also, some equations incorporate factors of safety to ensure that bed movement does not occur.

Results yielded an acceptable range of velocities for bankfull discharge conditions (Table H-19). Existing project constraints and required tie-in points throughout the restoration project area dictated the values for the selected design slopes. Variations in slope between reference reaches and project reaches account for the difference between average calculated mean velocity and selected design mean velocity.

Despite these limitations, selected design velocities lie within the acceptable range for mean velocity. For those values less than the acceptable range, it may be necessary to adjust other hydraulic variables such as width-depth ratio so that the proposed channel does not experience aggradation. For those values greater than the acceptable range, it may be necessary to increase channel roughness with larger substrate or increase the width-depth ratio.

Table H-18. Summary of estimated Manning's roughness values for selected reference reaches and proposed reaches at bankfull discharge.

Method	CFR3 Middle C4	CFR1 Bandmann F3/1	BFR1 Bonner B3	BFR Ovando C4	BFR Ovando B3	BFR Ovando F4
Average of Methods	0.032	0.034	0.039	0.036	0.039	0.036
Selected Design Roughness	0.032-0.035	0.040	0.037	N/A	N/A	N/A

Table H-19. Comparison of critical velocity and calculated velocity (ft/s) for selected reference reaches and proposed project reaches.

Velocity Method	CFR3 Middle C4	CFR1 Bandmann F3/1	BFR1 Bonner B3	BFR Ovando C4	BFR Ovando B3	BFR Ovando F4
Manning (Q_{bf})	5.7	7.2	6.6	4.9	4.6	5.0
Manning (Q_{bf})	5.5	7.1	6.1	5.4	5.2	5.3
Manning (Q_2)	6.2	8.1	6.9	6.3	5.9	6.2
Manning (Q_{10})	7.8	9.8	8.2	6.8	6.4	7.1
Manning (Q_{25})	8.5	10.4	8.7	7.2	6.8	7.7
Manning (Q_{50})	8.9	10.8	9.0	7.8	7.1	8.5
Manning (Q_{100})	9.3	11.1	9.2	8.4	7.3	9.1
Manning (Q_{500})	10.2	11.5	9.7	10.3	7.4	11.0
Average of Methods (Q_{bf})	5.3	6.4	6.9	5.1	5.2	5.1
Selected Design Velocity (Q_{bf})	5.8	7.0	6.4	N/A	N/A	N/A

Hydraulic Geometry Analysis

A hydraulic geometry assessment was completed for the selected reference reaches and proposed project reaches. The assessment compared results predicted by applicable regime equations with measured values from selected reference reaches. Average results were used as guidance for developing width-depth ratios for proposed channel cross sections. Efforts focused on developing stable riffle cross section dimensions.

Results produced a wide range of values (Table H-20). As mentioned previously, differences in experimental conditions under which the equations were developed is a likely cause for the variability. However, the average of all methods when compared to actual reference reach values produced an acceptable range of values. When selecting design values for modeling, consideration was given to regime equations however, greater emphasis was placed on observed values from reference reaches.

Table H-20a. Comparison of width and mean depth (ft) for selected reference reaches and proposed project reaches.

Geometry Method	CFR3 Middle C4			CFR1 Bandmann F3/1			BFR1 Bonner B3		
	W	D	W/D	W	D	W/D	W	D	W/D
Average of Methods	142	4.3	34	263	6.4	43	186	6.0	36
Average of Reference Reaches	141	3.1	45	238	6.2	38	200	5.1	39
Selected Average Design Value	150	3.7	40	245	6.1	40	200	4.9	40

Table H-20b. Comparison of width and mean depth (ft) for selected reference reaches.

Geometry Method	BFR Ovando C4			BFR Ovando B3			BFR Ovando F4		
Average of Methods	137	4.9	28	132	5.1	26	139	4.8	29
Average of Reference Reaches	170	2.9	59	191	3.0	64	183	3.0	61

Critical Shear Stress Analysis

A critical shear stress analysis was completed for selected reference reaches. Hydraulic models were developed using HEC-RAS (USACOE, 2004) to estimate average total shear stress. As indicated previously, the model was calibrated by using field-surveyed channel geometry, bankfull indicators, and bankfull discharges to predict Manning's roughness values.

Most available methods for calculating critical shear stress use the Shields equation, but differ in their means of calculating critical dimensionless shear stress. There are numerous critical dimensionless shear stress equations that have been developed to predict incipient motion. Equations are generally derived from laboratory flume experiments that use sand bed channels to develop sediment transport relationships. Models based on field data collected in alluvial, gravel-bed rivers are less common.

Results yielded an acceptable range of critical shear stress values for bankfull discharge conditions (Table H-21). When compared with actual shear stress values, average critical shear stress values correspond closely to actual shear stress at Q_2 indicating that incipient motion is likely to occur at discharges slightly above bankfull. Assuming that the bankfull discharge is responsible for incipient motion, it could be concluded that the reference reaches are experiencing aggradation although significant aggradation was not observed in the reference reaches and variation among the results could indicate that dynamic equilibrium can occur within a range of shear stress values. In fact, the higher critical shear stress could be a result of bed armoring which was observed at all sites. Assuming similar bed composition for the proposed design reaches, design shear stress values at Q_{bf} are within the range of average critical shear stress values calculated in the reference reaches.

Table H-21. Comparison of critical shear stress and actual shear stress (lbs/ft^2) for selected reference reaches and proposed reaches.

Shear Stress Method	CFR3 Middle C4	CFR1 Bandmann F3/1	BFR1 Bonner B3	BFR Ovando C4	BFR Ovando B3	BFR Ovando F4
Average of Methods (Q_{bf})	0.62	1.12	1.22	0.75	0.85	0.80
Actual Shear Stress (Q_{bf})	0.43	0.79	0.95	0.57	0.66	0.62
Actual Shear Stress (Q_2)	0.51	0.98	1.16	0.73	0.87	0.79
Actual Shear Stress (Q_{10})	0.70	1.35	1.57	0.91	1.07	0.96
Actual Shear Stress (Q_{25})	0.80	1.51	1.73	1.11	1.26	1.13

Table H-21 (Continued). Comparison of critical shear stress and actual shear stress (lbs/ft^2) for selected reference reaches and proposed reaches.

Shear Stress Method	CFR3 Middle C4	CFR1 Bandmann F3/1	BFR1 Bonner B3	BFR Ovando C4	BFR Ovando B3	BFR Ovando F4
Actual Shear Stress (Q_{50})	0.87	1.61	1.84	1.37	1.40	1.32
Actual Shear Stress (Q_{100})	0.92	1.71	1.94	1.65	1.56	1.48
Actual Shear Stress (Q_{500})	1.04	1.88	2.14	2.46	1.59	2.02
Design Shear Stress (Q_{bf})	0.53-0.81	1.19	0.92	N/A	N/A	N/A

Sediment Transport Analysis

There are numerous equations that have been developed to predict sediment transport rates. Equations are generally derived from laboratory flume experiments that used sand bed channels to develop sediment transport relationships. Models based on field data collected in alluvial, gravel-bed rivers are less common. Applied methods were selected for their applicability to gravel bed rivers.

Sediment continuity analyses were completed through a comparison of average sediment transport rates (all methods) for the selected reference reaches and proposed design reaches (Table H-22). Modeling results provided a wide range of values for sediment transport rates. As indicated previously, this is common with sediment transport analyses. Results were found to be sensitive to slight changes in input variables. Given this sensitivity and unacceptable range of values, conclusions focus on degree of sediment continuity between upstream and downstream reaches. Results for existing and proposed conditions indicate that sediment transport capability increases in the downstream direction, implying that conveyance is adequate and reaches are not aggrading.

Table H-22. Comparison of average sediment transport rates (tons/day) for selected reference reaches and proposed reaches at selected discharges.

Reach	Q_{bf}	Q_2	Q_{10}	Q_{25}	Q_{50}	Q_{100}
Existing Conditions						
CFR3 Reference	45,171	73,185	169,926	231,771	268,496	313,069
BFR1 Bonner Gage Reference	88,602	145,759	287,122	355,117	408,038	457,252
Confluence (CFR3 + BFR1)	133,773	218,944	457,048	586,889	676,533	770,321
CFR1 Bandmann Reference	171,965	285,354	590,006	745,151	856,330	984,317
Percent Difference Existing Conditions	**22%**	**23%**	**23%**	**21%**	**21%**	**22%**
Proposed Design Conditions						
Proposed CFR3/2	53,652	77,787	152,687	192,730	220,859	248,191
Proposed BFR1	98,087	162,663	345,594	439,916	507,753	574,206
Confluence (CFR3/2 + BFR1)	151,739	240,449	498,281	632,646	728,613	822,396
Proposed CFR1	167,571	292,813	659,178	862,949	1,019,354	1,171,173
Percent Difference Proposed Conditions	**9%**	**18%**	**24%**	**27%**	**29%**	**30%**
Upstream Comparison						
CFR3 Reference	45,171	73,185	169,926	231,771	268,496	313,069
Proposed CFR3/2	53,652	77,787	152,687	192,730	220,859	248,191
Percent Difference Upstream Conditions and Proposed CFR3/2 Reach	**19%**	**6%**	**-10%**	**-17%**	**-18%**	**-21%**
Downstream Comparison						
Proposed CFR1	167,571	292,813	659,178	862,949	1,019,354	1,171,173
CFR1 Bandmann Reference	171,965	285,354	590,006	745,151	856,330	984,317
Percent Difference Proposed CFR1 and Downstream Conditions	**3%**	**-3%**	**-12%**	**-16%**	**-19%**	**-19%**

In summary, a range of 3 to 30 percent difference in average sediment transport capability was observed. Again, this range is attributed to the sensitivity of the methods to slight changes in input variables and transitions in valley morphology. Except for existing conditions results, the percent difference of sediment transport between reaches was observed to increase as discharge increased. Results for Q_{bf} and Q_2 produced the lowest range of reach-to-reach sediment transport differences. Given the sensitivity of the methods and range of differences for existing conditions (21 to 23 percent), the analysis appears to provide an adequate demonstration of sediment transport continuity between upstream, restoration project area and downstream reaches. However, further review of effects of sediment transport discontinuity will be evaluated during the final design.

Scour Analysis

A scour analysis was completed for the proposed project reaches to evaluate general scour and bend scour. General scour was analyzed to determine the required scour depth to re-form the armor layer in the new channel. Bend scour was analyzed to validate maximum pool depths.

Bend scour results yielded an acceptable range of values for bankfull discharge (Table H-23). Except for the CFR1 Bandmann reach, average results corresponded closely with observed maximum pool depths in the reference reaches. The observed maximum pool depth in the CFR1 Bandmann reach occurred on the outside of a bend near a bedrock outcrop. A similar bedrock outcrop is present in the proposed CFR1 design reach near the dam. For this reason, the observed value was given greater emphasis when selecting design values. A supplemental check of 100-year scour depths was performed for the CFR1 and BFR1 proposed reaches, yielding values of 24.1 ft and 20.3 ft, respectively. Further consideration will be given to 100-yr scour depths and associated design implications in Phase III final design.

Table H-23. Summary of predicted scour depths (ft) for selected reference reaches and proposed reaches at bankfull discharge.

Shear Stress Method	CFR3 Middle C4	CFR1 Bandmann F3/1	BFR1 Bonner B3	BFR Ovando C4	BFR Ovando B3	BFR Ovando F4
Range of Values	5.9 - 9.9	10.3 - 13.5	7.7 -9.9	5.9-11.9	5.2 - 6.6	5.2 - 9.3
Avg Bend Scour	7.5	11.5	8.6	7.4	5.6	6.6
Observed Pool Max Depth	7.5	23.8	N/A	7.8	7.9	6.9
Selected Design	8.0 - 11.1	18.2 - 24.3	9.8 - 14.7	N/A	N/A	N/A

Modeling runs were completed to assess hydraulic and sediment transport conditions in the existing reaches and for the design channel dimensions. A more complete discussion of the models, results, and output interpretations are included in Appendix C.

H.2.2.3 Draft Design Dimensions

The following section includes the draft design dimensions for the proposed restoration project area. Riffle cross-section dimensions (Table H-24), planform geometry (Table H-25), and profile dimensions (Table H-26) are included below. Run, glide, and pool dimensions are included in Appendix K.

Table H-24. Selected riffle cross-section dimensions for proposed reaches at bankfull discharge.

Channel Variable	BFR1	CFR1	CFR2	CFR3
Stream Type	B3c	B3c	B3c	C4
Width (ft)	186-206	231-255	138-153	141-156
Mean Depth (ft)	4.7-5.2	5.8-6.4	3.5-3.8	3.5-3.9
Maximum Depth (ft)	6.2-7.5	8.3-8.7	4.6-5.6	4.7-5.7
Area (ft^2)	960	1480	530	550
Width-Depth Ratio	36-44	36-44	36-44	36-44
Floodplain Width (ft)	240 - 280	275 - 330	300 - 900	900 - 3000
Entrenchment Ratio	1.2-1.4	1.1-1.2	1.8-2.5	6 - 20

Table H-25. Selected pattern dimensions for the proposed project reaches.

Characteristic	BFR1	CFR1	CFR2	CFR3
Stream Type	B3c	B3c	B3c	C4
Meander Radius (ft)	N/A	N/A	N/A	450 - 750
Radius/Wbf Ratio	N/A	N/A	N/A	3 – 5
Meander Length (ft)	N/A	N/A	N/A	1,500 – 2,400
Meander/Wbf Ratio	N/A	N/A	N/A	10-16
Stream Length (ft)	6,000	5,500	4,000	9,500
Valley Length (ft)	5,900	5,200	3,600	7,300
Sinuosity	1.00 – 1.10	1.00 – 1.10	1.10-1.20	1.20-1.30
Belt Width (ft)	400 - 800	500 – 1,000	600 – 1,200	1,200 – 1,800
Meander Width Ratio	2 - 4	2 - 4	2 - 4	8 - 12

Table H-26. Selected channel profile dimensions for the proposed project reaches.

Characteristic	BFR1	CFR1	CFR2	CFR3
Stream Type	B3c	B3c	B3c	C4
Average Valley Slope (ft/ft)	0.0026	0.0031	0.0043	0.0032
Average Channel Slope (ft/ft)	0.0025	0.0030	0.0036	0.0027
Pool Spacing (ft)	800 - 1,200	1,000 - 1,500	450 - 750	450 - 750
Pool Spacing-Width Ratio	4 - 6	4 - 6	3 – 5	3 - 5

H.2.3 Channel Construction Methods

H.2.3.1 Channel Construction

The CFR and BFR channels will be constructed to the selected cross section dimensions, planforms, and profiles in order to convey the flows and transport the sediment made available by the watershed. The reconstructed channels would be designed to minimize lateral channel migration in portions of the restoration project area where the channel parallels contaminated sediments. Reconstructing the channels in the restoration project area will improve the amount of fish habitat, increase the amount of river-floodplain interaction, and provide sufficient energy dissipation. A comprehensive revegetation plan will be implemented to promote a vigorous riparian community that will provide long-term bank and floodplain stability, riparian and aquatic habitat, and woody debris recruitment to the river.

A two-stage channel will be constructed through the restoration project area. A two-stage channel includes a bankfull channel to convey the flow and sediment associated with the channel-forming (bankfull flow) discharge event and a floodplain designed to accommodate flows of greater magnitude, including the 100-year flood. Channel-floodplain interaction would reduce in-channel water velocities, shear stress, and bank erosion at higher discharges. Constructed floodplains would serve to moderate flood peaks, store fine sediment, and increase late-season base flows.

Construction within the restoration project area will vary between complete and partial channel and floodplain construction. Complete construction will require rebuilding the floodplain following the removal of contaminated sediments. The new channel will be built with fill that is imported into the restoration project area. Partial channel and floodplain construction will involve constructing the channel within the existing floodplain. Depending on the location, channel construction will require greater channel stabilization measures to minimize lateral channel adjustment.

Bank stabilization, grade control, step-pool, and fish habitat structures will be constructed using large woody debris, large rock, and coarse alluvium (see Appendix L for typical structure design details). Although some bank stabilization structures will be designed to emulate naturally occurring habitat arrays found in stable stream reaches, several of the grade control structures do not have natural analogs. Higher gradient confined channel reaches on the lower BFR and CFR will be constructed with additional grade control structures. Descriptions of proposed structures are included in the following sections.

H.2.3.2 Channel Grade Control and Bank Stabilization Methods

The restoration plan for rebuilding the CFR will require stabilizing the reconstructed channel with structures. Maintaining both vertical and lateral channel stability will be necessary to maintain channel-floodplain connectivity and to limit the scour of contaminated sediments to be left in-place on the CFR floodplain. Grade control and bank stabilization structures will be built at select locations to maintain vertical and lateral channel stability. Structures will be placed in the range of morphological channel features to affect habitat feature stability, sediment sorting,

and aquatic habitat diversity. Structures will also be used in combination and where appropriate, bioengineering techniques will be incorporated with large wood and rock structures. A discussion of bioengineering treatments is included in Appendix G.

Structure composition, placement, and size will vary throughout the restoration project area. Although most of the structures will be designed to blend with the surround river corridor, several of the larger grade control structures will be built more so for maintaining vertical and lateral channel stability than for aesthetics. The following sections highlight the types of grade control and bank stabilization structures that will be built on the CFR and BFR.

H.2.3.3 Channel Grade Control Structures

Various grade control structures are prescribed for the restoration project area. Grade control structure types and locations would vary according to specific project reaches and project goals. Structures will address bed stability concerns, increase fish habitat distribution, and provide recreational boating opportunities where appropriate.

The grade control structures will maintain the designed channel profile elevations. The structures are also designed to improve flow convergence and sediment transport during high flows. Vane arm gradient and angle from the bank affect the hydraulic head the structures create. A steeper vane arm gradient results in greater hydraulic acceleration over the structure and into the pool created by the structure. This acceleration is necessary for maintaining sediment transport through the pool and subsequently, the depth of the pool. The vane arm gradient and arm length also affect the degree of bank protection created by the grade control structure. A longer, flatter vane arm protects a greater bank distance than a short, steep vane arm.

Rootwads and other large woody debris are typically incorporated into the grade control structures to increase the habitat diversity in the pool. Woody materials are anchored in between or below the vane arms. Material positioning influences vane hydraulics and pool scour, creating a range of aquatic habitats in the restoration project area.

The designed structures would allow for fish passage. Fish passage is typically a concern during base flows when portions of the stream may become disconnected if the streambed is too wide and the water too shallow. Each grade control structure would be designed to have no more than 0.5 ft. to 1.0 ft. of drop (water surface from the structure throat to the water surface downstream) during base flow conditions. Gaps between structure rocks would also allow fish passage from the pool downstream, upstream through the structure. During the majority of the hydrograph, water depths over the vane structures would be sufficient for all species and most age classes to navigate the structures.

Rock Cross-vanes
Cross-vanes provide long-term grade control in reconstructed stream channels. Natural channels maintain grade control through undulations in the bed profile. It is necessary to include grade control in reconstructed channels due to the non-sorted, non-armored nature of channel material following construction. Cross-vanes would be built according to design channel dimensions and

include footer rocks to prevent undermining of the structure during high flows. Constructed scour pools below the cross vane structure will enhance fish habitat and create pools for over-wintering of the resident fishery.

Rock W Weirs
W weirs are commonly used to split flow into more than one channel and also to protect bridge abutments within the active channel. The design of the W weir is similar to the cross-vane in that both sides of the structure have vane arms that slope down from the approximate bankfull elevation upstream to a point where the vane intersects the channel bed. The W weir divides the river into fourths with the vane arms intersecting the bed at one-fourth and three-fourths of the channel width (Rosgen 2001). The center portion of the structure rises in elevation in the downstream direction to form a W looking from upstream to downstream. The multiple vane arms and center structure increase the number of flows paths, diversifying aquatic habitat around the structure. W weirs maintain deep pools in a similar manner to the aforementioned vanes and cross-vane.

Where bridge piers and abutments will be exposed to free flowing river conditions on the BFR and CFR, W weirs are proposed upstream of bridges as flow redirective structures. W weirs are designed to split the flow around a pier thus creating an area of lower shear stress and reduced local scour at the pier. The structure's vane arms adjacent to the banks mitigate contraction scour in a similar manner by redirecting the flow toward the openings between piers. Results of laboratory experiments (Johnson, et. al. 2001) showed that vanes appropriately placed in a stream channel upstream of a vertical wall bridge abutment moved the abutment scour away from the bank and toward the center of the channel. The same experiments developed parameters for structure orientation that maximize redirective benefits. In addition, the experiments concluded that the structures performed effectively over a range of flow conditions.

Armored Tailouts
Natural stream channels sort and transport bed material in a manner that provides for natural grade control. In some areas of the project, channel materials would be sorted during construction to generate material ranging from the D_{84} – D_{100} of the channel bed material. Additional materials may be imported to the project site depending on the availability of on-site materials. These materials would be placed in the designed bed profile to provide grade control at pool tailouts. Cobble tailouts may also be used in lieu of cross-vanes where additional long-term grade control is not necessary.

H.2.3.4 Bank Stabilization Structures

Bank stabilization structures are necessary for maintaining bank integrity on restored stream reaches until planted vegetation is capable of providing natural bank stabilization. Structures are expected to last for a limited period of time until vegetation provides bank stability into the future. Bank stabilization structures also serve to diversify available fish habitat. Prescribed structures provide overhead cover, flow path complexity, interstitial hiding spaces, and visual separation for fish. Species and age-classes typically segregate according to these microhabitat attributes to reduce inter-size-classes and inter-species interactions.

Engineered Log Jams
Engineered log jams are constructed to mimic naturally occurring woody debris jams that typically form in the lower one-third of meander arcs. Natural jams form over time as high water events overtop the lower portion of the meander, depositing wood on the floodplain. Large wood traps smaller materials, increasing the volume of the jam. Jams create diverse aquatic and overhead habitat for fish, riparian habitat for mammals, and perches for birds. Sizable jams provide bank protection and promote vertical scour that increases the distribution of pool habitat. Gravel sorting promotes spawning gravel retention and pool tailout vertical stability.

Constructed woody debris jams are built with several large trees, various sizes of rootwads, small diameter woody material, and large anchor rocks. The large trees are tied into the bank and anchored with large rocks primarily placed below the floodplain surface. Other woody material is interlaced among the large key trees to create a diverse array of woody material. Several rootwads and logs are extended out into the channel to diversify the local aquatic environment.

Rootwad Composites
The purpose of bank placed rootwads is to dissipate water velocities and shear stress along the channel margin, especially on the outside of meander arcs. Rootwad composites provide localized habitat diversity and provide bank strength until riparian vegetation becomes established. Rootwad composites consist of a footer log, anchor rocks, multiple rootwads, and additional habitat logs. Spacing between rootwad composites and other structures depends on bank stabilization and fish habitat objectives. Rootwads would often be used to complement other structures to increase the amount of bank protection provided by the complementary structure. Each rootwad revetment would have two to four mature willow transplants with attached root masses placed around the point of streambank intersection. Additional plantings would also be completed to improve the long-term natural bank stability. Complementary woody debris would be added to the rootwad revetments to increase fish habitat and bank protection.

Log and Rock Vanes
Rock vanes and log vanes will be incorporated in the design to improve bank stability and enhance fish habitat diversity. For CFR3 and the upper end of CFR2, emphasis will be made to minimize the frequency of rock structures and incorporate as much wood into the construction as possible. J-hook vanes consist of footer rocks placed below the maximum scour depth and an additional layer of rocks placed on top of the footer rocks. Rock sizes will range from 1 yds^3 to 2 yds^3. Log vanes consist of a single log extending from below the maximum scour depth of the channel to a point on the bank that is 0.5 ft to 2.5 ft below the bankfull elevation. Logs will be anchored with buried large angular rock. Vane lengths will vary by location, however, all vanes will be placed in an upstream direction at an angle of 20^o to 25^o from the bank. Habitat logs and rootwads will protrude into the scour pool to increase fish habitat. Transplanted sod mats and other methods described in the revegetation section of this report will be completed to provide floodplain stability.

H.2.3.5 Additional Channel Habitat Structures

Additional channel habitat structures are planned for the higher gradient, confined channel sections of the lower CFR and BFR (CFR1, CFR2 and BFR1) where the channel profiles are somewhat steeper, the valleys narrower, and the channel pattern will be straighter. The prescribed structures will require large rock and woody debris similar to the aforementioned grade control and bank stabilization structures.

Converging Rock Structures
Converging rock structures will be used to provide flow convergence in riffles and at riffle-to-run transitions. The structures are comprised of multiple boulder clusters that narrow the channel thalweg creating elevated velocities. Structures will be built with at least two rock downstream-facing offsetting vane arms. A rootwad may also be used in place of a rock vane. The arms deflect the flow back and forth and create eddies on the downstream side of each arm. A standard rock cross vane is positioned downstream of the rock arms. The vane deflects the thalweg back towards the middle of the channel. The structure would allow fish passage at all flow levels.

Wing Deflectors
The single and double wing deflectors are built with large rock in-filled with finer material. Single wing deflectors are offset from each other to deflect the current down the length of the treated reach. The double wing deflectors concentrate the flow to the middle of the channel with a subsequent acceleration of water between the narrowed channel. The elevated water velocities increase the shear stress and scour potential. A large deep pool is typically maintained downstream of the double wing deflectors. The pool would provide fish habitat and would allow fish passage at all flow levels.

Random Rock Cover
Similar to the converging boulder clusters, the random rock cover diversifies the channel and flow paths. Boulder clusters offer obstacles for boaters and create variable currents for fish. The structures are expected to provide diverse fish habitat without affecting fish passage.

H.2.4 Reach-specific Restoration Treatments

The following sections provide specific details about the recommended treatments for the proposed restoration project area. Recommendations focus on treatments including proposed channel types, rationale for proposed alternatives, grade control structures, bank stabilization structures, and revegetation. Only structures deemed critical for coordinating with the Remediation Actions are addressed in detail in the following section. Such structures are identified to allow for review and comment by the peer review panel. Additional structure details will be finalized in the Phase 3 design. A channel stability assessment was completed to evaluate the feasibility of design alternatives and validate the selected design criteria (see Appendix C).

H.2.4.1 CFR 1 Proposed Treatments

CFR1 includes the CFR from Milltown Dam downstream to the Interstate 90 bridge. The Remedial Action (RA) includes removing the powerhouse, radial gates, divider block, and right abutment wing wall in addition to Milltown Dam. This will allow the construction a B3c channel with a floodprone width of approximately 600 feet. The powerhouse and associated structures will be removed to a depth approximately 5 ft lower than the proposed finished grade of the channel. The proposed CFR channel at the confluence with the BFR will bend gradually to encounter the rock cliff at which point a large rock cross vane grade control structure will be placed at station 50+00 to establish the gradient for the entire upstream segments of both the BFR and CFR. The rock cross vane will be keyed into any remaining segments of the removed structures and wing wall to provide long-term floodplain stability. Sheet L-8 in Appendix L illustrates the configuration of proposed grade control structures in the vicinity of the dam. The cross vane will be keyed into the underlying bedrock and into the rock cliff on the south side of the channel.

The proposed alignment, gradient, channel configuration, and depth are similar to pre-dam conditions based on surveys conducted in 1905 as shown in Figure E-13 through E-15, Appendix E (K. Ross Toole Archives, Montana Power Collection, University of Montana Library). The floodprone area is somewhat less than pre-dam conditions due to land development along the northern edge of the historical floodplain. The channel alignment downstream from the dam will also be similar to historical conditions based on the pre-dam construction sketch that suggested that the island downstream from the dam was in place prior to dam construction. Thus, the channel will divide into two channels around the island with the main channel to the north, or river right side of the channel (Appendix K, Figures K-3 through K-5 illustrate dimensions). A W weir is proposed to provide grade control and split the channels at the upstream end of the island (station 45+00) as shown in Figure L-8. Between the cross vane and W weir, the spillway will be removed to a depth approximately 5 feet below the predicted maximum pool depth (or bedrock if encountered before maximum depth is reached) to provide a margin of safety for additional scour that will occur during flood events. The large existing scour pool downstream from the spillway will fill and adjust its dimensions naturally by river bedload.

The powerhouse area and the large existing pool downstream will be filled and graded with material from upstream of the divider block to form a sloping floodprone area blended into the existing ground. Both channels will be stabilized with rock structures and two weirs are proposed to protect the railroad piers and improve hydraulics and sediment transport through the bridge section. Actual channel construction will end just downstream from the island where the two channels converge. If necessary for grade control, a cross vane will be constructed at station 30+00, which is approximately 200 to 300 feet downstream from the split channel convergence. From this point downstream, the existing channel appears to be in equilibrium and functioning well. At this point, the river transitions into a stable F3 stream type. No other work is proposed downstream from station 30+00.

Reach CFR1 would have a mean gradient of about 0.0031ft/ft. The minimum flood prone width for this channel is about 600 ft at the upstream end narrowing to about 250 ft by station 29+00.

Only structures deemed critical for coordinating with the Remediation Actions are addressed in detail in the following section. Such structures are identified to allow for review and comment by the peer review panel. Additional structure details will be finalized in the Phase 3 design. Structures proposed in this reach would function to provide grade control, bank stabilization, fish habitat complexity, and river floating. Due to the river size and anticipated bedload transport, the structures would be constructed primarily of large rock. The possibility exists to incorporate large woody debris and root wads into most structures for habitat. Typical structure drawings are included in Appendix L.

Upstream from the dam site, scour analyses (Envirocon, 2004) predicted that the channel will scour the finer deposited sediments to native alluvium, near the proposed mean bed elevation. Channel shaping and structure placement in this reach will be completed during the Phase 3 design, but actual channel placement must wait until after the Remediation Action stage 3 drawdown (see Section H.2.5 for project timeline). The channel upstream from the dam site to the confluence with the BFR may need to be reshaped as structures are placed. Since all channel features upstream from the dam site will not have been subjected to the normal shear stresses that occur during normal runoff events, grade control and bank stabilization structures would need to be constructed at the proposed frequency to prevent channel incision and bank erosion until the bed surface armoring becomes re-established and riparian vegetation matures. These structures are designed to allow fish passage upstream and downstream at most flow conditions present when the fish are conditioned to move. Also, boating opportunities are possible with the proposed structures. Grade control structures constructed with large rock are appropriate in this geomorphic setting with the south bank encountering a bedrock outcrop.

H.2.4.2 CFR2 Proposed Treatments

Reach CFR2 will be constructed as a meandering gravel bed channel (C4 stream type) in the upper half of the reach, transitioning into moderately confined, straighter gravel bed channel (B3c stream type) for the lower half of the reach. Floodplain widths would also transition from a width of 1,000 ft at the Duck Bridge grade to approximately 300 ft near the confluence. One of the objectives of both the RA and RP is to balance channel excavation and fill volumes within the restoration project area. Terraces in CFR2 will be constructed to use excess material that is excavated in the reach. The first terrace will be a narrow low terrace about 2 ft higher than the floodplain. A second higher terrace will slope to the existing grade remaining after contaminated sediment removal. The terraces serve the following functions.

- Gradually narrow the floodplain width consistent with the design channel dimensions to transition from a meandering channel (C4 stream type) to a moderately confined channel (B3c stream type).
- Provide additional protection to the SAAIII-b sediments that will remain to the south of the proposed CFR channel alignment.
- Provide additional protection to the Interstate 90 fill slopes to the north of the proposed CFR channel alignment.
- Balance the final cut and fill quantities after sediment removal and floodplain channel and re-grading of the existing sediments has been completed.

Wetland depressions consistent with the valley morphology were designed to optimize the wetland credits for the area. These wetlands are designed to mimic abandoned river oxbows and are carved into the floodplain and terraces. However, floodplain stability is of primary concern in the short-term until vegetation can stabilize the area and thus, the wetland depressions are discontinuous in a down-valley direction. The wetlands are designed to allow flood water to back up into the wetland, but not allow frequent floods to access the depressions from upstream. This concept will minimize the potential for flood flows through the wetlands to capture the wetland channels. The wetland depths are variable between 1 and 3 ft in elevation below the bankfull floodplain elevation adjacent to the wetland. In most cases, slopes are gentle into and out of the deepest point of the wetland, which occurs around the outside of the depression. This concept allows for the maximum vegetative diversity relative to the duration and elevation of groundwater. For more information on wetland design and revegetation plans, refer to Appendix G.

SAA II and III sediments with low contaminant concentrations would be graded to fill some of the volume created by the removal of the SAA I sediments. The SAA II sediments would be suitable for building floodplains and terraces. Also, since the Duck Bridge grade on the south side creates a constriction on the floodplain during major floods, the fill will be excavated down to the floodplain elevation and used as fill for the low areas. Removing the Duck Bridge fill will allow a smooth transition from a wider floodplain to a narrower floodplain that will eliminate the rapid constriction that occurs during major floods.

The Remediation Plan (Envirocon 2005) proposes to excavate the CFR2 channel into the pre-dam alluvium surface, which is assumed to be adequate for general bed material. However, coarse cobble and gravel will be imported or generated in the restoration project area to construct the channel and banks where pre-dam alluvium is not consistent with the design criteria.

The SAA III-b sediments that currently have relatively high contaminant concentrations would be slightly re-graded to provide drainage, and will then be revegetated in place (Envirocon 2005). This work will occur at the transition point between the B3c and C4 channel types. The floodplain narrows significantly at this point. SAA III-b would remain higher in elevation than the predicted 500-year flood level and would be isolated from flooding by deep fills and gentle, revegetated slopes. Sheets I-2 (Appendix I) and K-7 (Appendix K) illustrate the conceptual grading in this reach.

Floodplain gradient would range from about 0.0034 ft/ft in the upstream C4 valley portion to about 0.0042 ft/ft in the lower B3c valley portion. River gradient would range from about 0.0027 ft/ft in the upstream C4 valley portion to about 0.0036 ft/ft in the lower B3c valley portion. Structures proposed for the downstream B3c portion of this reach are primarily rock grade control and bank stabilization structures similar to those in reach CFR1. The gradient is steeper in this reach than in either the upstream or downstream reaches. Much of the new channel would be constructed on fresh fill that would not have the natural sorting and grade control of an existing river. To prevent the potential for channel incision and bank erosion, fairly high densities of structures will be required. The grade control structures are intended to create riffle-step morphology that would allow fish passage. Also, boating opportunities are enhanced

with the proposed structures. Selection and configuration of structures will be completed in the Phase 3 design.

The C4 portion of the reach would be stabilized primarily with large wood structures such as rootwad/log vane combination structures with rock J hook vanes and large woody debris jam structures. These structures are necessary for grade control and bank stabilization until the bed material can become naturally armored and bank vegetation matures. A rock sill is proposed at the upstream end of this reach, approximately where the Duck Bridge fill is to be removed to ensure that the newly constructed floodplain remains secure until the vegetation matures. The sill would be constructed at floodplain grade and is basically a trench excavated into the floodplain about three feet deep and filled with large rock. The sill is capped with sod or fill so that it is not visible. This sill could be incorporated into a foundation for a trail or link into proposed bridge abutments. Channel stability, hydraulics and sediment transport conditions for the proposed channel system are addressed in Appendix C.

H.2.4.3 CFR3 Proposed Treatments

The recommended condition for CFR3 will be a C4 stream channel. The upper half of CFR3 will be reconstructed to a predominantly single thread C4 channel with the existing CFR channels converted to discontinuous wetlands as those channels are partially filled with gravel and soil from the new channel excavation. The channel will be constructed so that the proposed floodplain elevations will match the existing floodplain elevations and established floodplain vegetation. The new channel will have hydraulic and meander geometry appropriate for the geomorphic setting and size of the river. Floodplain gradient would be about 0.0034 ft/ft over the total channel length. Whenever possible, the new channel would be constructed to re-activate abandoned oxbows and meanders that appear on the 1937 aerial photographs, the earliest available photographs. The upstream endpoint of the proposed restoration is the upstream end of CFR3-B. For more information on the rationale for selecting endpoints, see Section 4.3.

To maintain a consistent grade, the lower half of the CFR3 floodplain will be excavated into existing ground. At the downstream end of the reach, the floodplain elevation will be excavated into existing ground approximately 7 ft to maintain a relatively consistent floodplain gradient through the reach. The floodplain gradient would remain consistent throughout Reach CFR3. The width of the floodplain would gradually be reduced from greater than 2,000 ft to about 1,000 ft at the downstream end of the reach. The narrowing of the floodplain will continue downstream into reach CFR2 to allow a moderate floodplain transition during large flood events.

The transition to a more confined floodplain would be similar to historical conditions and will also greatly reduce the amount of fill required in CFR2 by lowering the entrance elevation into the reach. Initial estimates indicate that the earthwork will balance in the upstream portion of this reach, but the lower portion will result in an excess of about 200,000 cubic yards. It is proposed that excess excavated material be used to fill the floodplains in CFR2. Material with contaminant concentrations exceeding the desired contamination levels will be treated to meet the objectives. Whenever possible, existing vegetation will be salvaged and transplanted to the new floodplain elevation.

In addition to reconstructing the CFR3 channel, it will be necessary to construct a new channel for Deer Creek, a small tributary to the CFR on the south side of the CFR near the Duck Bridge. Deer Creek has been identified as an important spawning stream for westslope cutthroat trout by MFWP (P. Saffel, MFWP, personal communication). Since the floodplain for CFR3 will be lowered by up to 7 ft at the confluence point with Deer Creek, near station 94+00, Deer Creek will need to be reconstructed to provide a stable and productive stream consistent with the geomorphic setting that will match elevation with the CFR at the confluence. The proposed channel is a sinuous, unconfined single thread channel (E4 stream type) that would be approximately 6 ft wide and about 1 ft deep. The new channel will be constructed within the existing wetland swale as shown in Appendix I. Design dimensions, alignment, and details for Deer Creek will be determined in the Phase 3 design.

Four potential channel alignments have been identified for CFR3. All fit within the selected range of design dimensions as shown in Sheet I-6 in Appendix I. Since each alignment has specific construction requirements and different effects on landowners, the final alignment will be determined during the Phase 3 design. Lengths and gradients of the four options do not vary significantly. Alignment C was selected to evaluate hydraulics, channel stability, and sediment transport for CFR3.

New channel construction will require bank stabilization and grade control until the vegetation can mature. Bank stabilization is necessary not only for stable function of the designed channel, but also to minimize erosion of contaminated sediments left in-place. Most of the proposed grade control and bank stabilization objectives will be accomplished with structures constructed predominantly of wood, such as rootwad/log vane combinations, rock J hook vanes, and engineered log jams. Certain grade control objectives could be accomplished with armored pool tail out structures composed of the largest rock found in the existing bed. Structure spacing will be calculated based on structure size, gradient, and stream meander geometry. The grade control structures are designed to match the pool-to-pool spacing common in C4 channels. These structures are designed to function naturally in this geomorphic setting and match the natural stream aesthetics. Fish passage and habitat enhancement are also designed into these structures.

The existing wetlands along the southern portion of this reach will not be graded. It is anticipated that these wetlands and old channels will remain at the low terrace elevation and will be fed by subsurface water from adjacent hill slopes and flood water from the upstream portion of the reach. These wetlands will likely be intermittent with less surface water supplied from the main channel. The existing stream channels will be filled partially, leaving sections of unfilled channel that will be converted to shallow wetlands. It is anticipated that these wetlands will receive water during flood events and when the water table is elevated. To minimize the potential for colonization by undesirable non-native fish species, these wetlands will remain disconnected from the main channel during baseflow conditions.

The downstream portion of CFR3 will need to be completed before CFR2 finish work and structures are initiated. Water will most likely be diverted into the north branch of the existing CFR channel system during construction of the inset floodplain. At that point, the river will continue to flow through the bypass channel constructed during RA. Construction logistics will be finalized in the Phase 3 design.

H.2.4.4 BFR1 Proposed Treatments

BFR1 will need to incorporate several actions that are not considered restoration actions and will be implemented by others during the entire project construction period. These actions include:

- Stimson Dam removal and associated channel stabilization.
- Grade stabilization of highway and railroad bridge crossings.
- Three-stage drawdown of the reservoir and the associated scour that will occur during drawdown.

Stimson Dam will be removed early in the construction process during stage 1 drawdown. The bridge grade controls for Interstate 90 will be completed during stage 2 drawdown. The remainder of the channel construction to the upstream terminus will be completed during stage 3 drawdown. The upstream terminus of construction is the Stimson Dam, although some of this reach may not need much work due to the predicted scour. Actual channel construction in the reach upstream from the county footbridge to Stimson Dam will be determined during Phase 3 design.

It is recommended that BFR1 be converted from an F4 stream type with backwater conditions to a B3c stream type with step-pool morphology and a narrow, well-vegetated flood prone area similar to upstream reference conditions. Scour of the existing sediment deposits will occur during stage 3 drawdown (Envirocon, 2004). Scour is expected to occur down to the pre-dam alluvium elevation in the vicinity of the bridges. The resultant bed elevation after scour is predicted to be similar to the mean proposed channel bed elevation. The resulting channel and floodplain will likely need to be reshaped to the design dimensions. This will be accomplished by reshaping the existing bed material, where necessary, and grading a sloping floodplain. It is likely that earthwork can balance in this reach. The gradient will be consistent throughout the reach at about 0.0025 ft/ft.

BFR1 downstream from the Interstate 90 bridges to the confluence with the CFR will undergo scour during stage 3 drawdown. The scour analysis (Envirocon, 2004) predicted that scour will occur down to the depth of alluvium, near the proposed mean bed elevation. Channel shaping and structure placement in this reach will be determined during the Phase 3 design. However, channel alignment must wait until after stage 3 drawdown scour. This reach of channel may need to be reshaped as structures are placed. Since all channel features upstream from the dam site will not have been subjected to the normal shear stresses that occur during normal runoff events, grade control and bank stabilization structures would need to be constructed at the proposed frequency to prevent channel down cutting and bank erosion until the natural sorting can take place and the vegetation matures. These structures are designed to allow fish passage upstream and downstream at most flow conditions present when the fish are conditioned to move. Also, river boating opportunities are enhanced with the proposed structures.

Only structures deemed critical for coordinating with RA are addressed in detail in the RP. Such structures are identified to allow for review and comment by the peer review panel. Additional structure details will be finalized in the Phase 3 design. Structures proposed in this reach would provide multiple benefits for various functions including grade control, bank stabilization, fish

habitat complexity and river floating. Since this reach is a large river and substantial bedload movement, the structures will be constructed primarily of large rock. Large woody debris and rootwads will be incorporated into most structures for habitat. Refer to Appendix L for descriptions and illustrations of the proposed structures.

It is recommended that two abandoned piers at the old Highway 200 Bridge crossing are removed to improve channel stability. In general, bridge spans are adequate to span the active channel and flood prone area, but the railroad bridge is skewed enough to reduce the effective capacity to convey flood flows. A series of rock w-weirs will be necessary to split the active channel around the piers while maintaining hydraulic function. W-weirs also reduce scour around piers and allow fish passage. Other channel structures would be similar to those on the CFR1 and CFR2, with rock steps constructed to provide grade control, allow fish passage, and provide boating opportunities.

H.2.4.5 Selected Floodplain Dimensions

For the lower half of CFR1 and the upper portion of BFR1, the floodplain is determined by the width of the high terraces that confine the floodplain. For the remaining reaches, floodplain dimensions were determined using the reference data from valley morphology reference reaches, other reference reach data, hydraulic modeling results and surveyed pre-dam cross-sections from 1905. The objective for the CFR3, CFR2 and BFR confluence is to slowly transition from a broad unconfined valley and floodplain in CFR3 to a confined and entrenched floodplain at the downstream end of CFR2. The confluence will be slightly wider to accommodate the additional flood flows, and then transition to the width of the confining terraces downstream from the railroad bridge in CFR1.

H.2.4.6 Selected Channel Dimensions

Selected channel dimensions are included in section H.2.2.3 Draft Design Dimensions.

H.2.4.7 Selected Channel Profile and Habitat Unit Slopes

Proposed floodplain gradients are presented in Appendix J. The longitudinal profile was developed with the objective of maintaining appropriate sediment transport, conveyance capacity, and keying the proposed floodplain to existing floodplains and vegetated features in areas that were not directly affected by backwater and deposition from Milltown Dam. Floodplain gradients were kept as constant as possible to minimize potential problems associated with flow acceleration. The proposed gradient is shown as a floodplain gradient at bankfull stage and a consistent bed profile that is parallel to the water surface profile. The bed gradient is not intended to illustrate pool, riffle, run and glide habitats, but rather to indicate the elevation of the grade control at any point in the profile. More detailed profiles will be developed during Phase 3 design.

<u>CFR Profile</u>
For the CFR reaches, the valley gradient is illustrated rather than the stream profile (Appendix J). With the variation in alternative channel alignments and a range of associated sinuosity values,

the longitudinal profile could vary significantly. For this reason, the valley profile is illustrated with the understanding that the channel gradient can be calculated by dividing the total change in elevation by the total channel length. For CFR3, the floodplain elevation (bankfull stage) in the upstream portion of the reach was determined by the topographic survey. The field determined floodplain elevation was located and surveyed in the existing channel systems. This floodplain elevation was also validated using the cross-sections that were derived from the topographic surface developed from both the land based surveys and aerial photogrammetry. A best-fit line was developed along the valley profile for the floodplain elevation and plotted on the CFR profile.

At approximately station 120+00 on the valley profile, the floodplain of CFR3 flattens corresponding to the backwater elevation of Milltown Dam during floods. The 1908 flood was calculated to have a maximum elevation of 3265.5 feet (Envirocon, 2005), which occurs at about station 125+00 feet on the profile. In other words, downstream from station 125+00, the 1908 flood caused contaminated sediment deposition and backwater conditions. It is possible that the deposition from the 1908 flood also caused head ward aggradation of the channel due to a flattened gradient at that point. However, the channel and floodplain system seem to have adjusted over the last century to a relatively consistent floodplain gradient upstream from station 125+00. The mean floodplain valley gradient for CFR3 upstream from station 120+00 is about 0.0032 ft/ft. Extending this trend line downstream to Duck Bridge would result in a floodplain elevation of about 3255.5 feet, which is about six to seven feet below the existing floodplain elevation. To maintain a consistent floodplain gradient for CFR3, the floodplain for the lower portion of CFR3 would need to be lowered 7 ft at station 94+00 and day-lighting at station 120+00.

During reservoir drawdown in 2004, three submerged tree stumps were observed at station 120+00. These stumps were anchored into the historical channel feature and have been preserved by being submerged in water since the dam was built. The stumps are about 4 ft below the proposed floodplain trend line, suggesting a lower historical floodplain elevation relative to the existing condition.

The same process was used for CFR1 downstream from Milltown Dam, where the bankfull stage indicators have stabilized since construction of the dam. Again, a best-fit line was developed along the valley gradient and extended upstream to the confluence with the BFR at valley station 56+00. The floodplain indicators were consistent with the best-fit line for a mean gradient of 0.0031 ft/ft, which is nearly the same as CFR3 upstream from station 125+00. However, if the CFR1 floodplain gradient trend line was extended upstream to station 120+00, it would fall about 4 ft below the CFR3 trend line at that location. Coincidentally, the CFR1 trend line elevation at station 120+00 lines up closely with the location of the tree stumps previously identified at station 120+00.

The CFR2 floodplain gradient was developed by connecting the CFR3 trend line at Duck Bridge to the BFR1 trend line at the confluence, a distance of 3,800 ft. The resultant line gradient is equal to 0.0043 ft/ft and results in an increase of the gradient at Duck Bridge.

Using the proposed floodplain elevation trend lines, the bed elevation was plotted on the profile based on the maximum riffle depth, which is the mean bed grade line. This bed grade line is not intended to show the actual bed construction with run, pool and glide habitats, but to indicate the mean bed grade elevation at any point in the valley profile. Comparing the CFR2 bed profile to the pre-dam alluvium sampling (Envirocon, 2005), CFR2 bed elevations are lower than the pre-dam alluvium surface. As such, the CFR2 channel would be excavated into the alluvium, meeting desired objectives. A portion of CFR2 where the channel would not be at the pre-dam alluvium elevation occurs between station 80+00 and 94+00. In this section, the pre-dam alluvium is deeper than the mean bed elevation based on the subsurface sampling. The sampling density was less in this area and the actual alluvium depth will need to be further evaluated. Also, minimal sub-surface sampling has been completed in the area upstream from Duck Bridge to develop a pre-dam alluvium layer. However, the sediment coring, the shift in trend lines between CFR1 and CFR3, and the elevation of the tree stumps indicate that the proposed floodplain elevation at Duck Bridge may be about 4 ft higher than historical conditions.

For the draft restoration plan, it was assumed that it would be less desirable to reduce the elevation at Duck Bridge by another four feet. This would result in significant additional costs to excavate the entire floodplain for an additional 5,000 ft upstream. It was assumed that the change in gradient at Duck Bridge could be accommodated by some additional grade control constructed throughout the CFR2 reach. However, it may require importing coarse material for constructing the streambed in the upper 1,600 ft of CFR2. These assumptions will be evaluated by the peer review group and additional data will be collected during Phase 3 designs. It was also deemed more important to be consistent with the downstream tie in points.

<u>BFR1 Profile</u>
Similar surface and subsurface data were available for developing the BFR1 profile. Since this reach is currently under backwater conditions, there is no survey information available pertaining to the floodplain elevations. The confluence elevation was determined by the CFR1 profile. The upstream bed elevation was estimated by the alluvium layer that was determined by Envirocon (SOW 2005) and CH2MHill (2004), assuming post-scour and with Stimson Dam removed. A straight best-fit line was estimated through BFR1 and extended upstream to about station 80+00, which is located upstream from Stimson Dam. This grade line was assumed to be the mean thalweg elevation. The maximum riffle depth was added to the thalweg elevation to determine the floodplain elevation. The resulting floodplain grade line has a consistent gradient of 0.0025 ft/ft. Again, the mean bed elevation does not include the habitat features that will be detailed in the Phase 3 design. The proposed grade line fits the predicted scour and alluvium surface line fairly well. The proposed mean bed elevation is close to the existing bed elevations at all bridges except the Burlington Northern-Santa Fe railroad bridge. The existing bed at the railroad bridge appears to be predominantly finer sediment deposition. More information regarding the work around Stimson Dam will be necessary to finalize the upstream portion of the longitudinal profile. It is anticipated that additional data and analyses will be completed by all parties prior to completing the design on the proposed bridge grade control structures. Removal of Stimson Dam and the scour related to stage 1 and stage 2 Milltown reservoir drawdown, will be monitored to refine the predictions. The upstream portion of the profile will be determined during the Phase 3 design.

H.2.4.8 Meander Geometry and Channel Alignment Alternatives

The channel planform geometry is a function of the bankfull discharge and the bankfull design width. The most probable channel patterns for the restoration project area reaches were determined from empirical models developed by Leopold et al. (1964), Williams (1986), Rosgen (1996), and a reference reach database as described in Appendix B.

The empirical models and analysis provided a range of values for channel pattern attributes rather than specific values for channel pattern. The channel patterns and locations may be adjusted to account for the final condition of the valley bottom following RA. Where feasible, the new channel will incorporate established vegetation to provide bank stability and habitat. Available data sources used to develop the channel alignments, longitudinal profiles and cross sections included the complete topographic basemap developed by RDG, additional surface and subsurface elevation models developed by Envirocon, historical channel cross-section data from the Milltown Dam area circa 1905, aerial photograph series, and other data summarized in Appendices B and D.

In BFR1 and CFR1 the channel characteristics were dictated by existing conditions and infrastructure constraints. There was limited valley width available for aligning these channel segments. The CFR2 alignment was developed from design criteria, but was also subject to certain construction constraints. The CFR2 alignment has not changed appreciably from the DCRP proposed alignment. Due to the wider valley bottom, four different potential channel alignments are possible in CFR3. All potential alignments fit within the selected range of design dimensions as shown on Sheet I-6 in Appendix I. Since each alignment has specific construction requirements and different effects on landowners, the final alignment will be determined during the Phase 3 design. Lengths and gradients of the four options do not vary significantly. Alignment C was selected to evaluate hydraulics, channel stability, and sediment transport for CFR3.

H.2.5 Project Timeline and Construction Sequencing

The project timeline and sequencing has changed substantially from the DRCP due to major changes in Remediation Action (RA) design. The entire construction time frame for RA has been reduced to about four years and the scope of the restoration project area has been reduced from six reaches to four reaches (Table H-27).

The timing of most work will ultimately be governed by the drawdown stages and RA schedule. The Scope of Work (SOW) document prepared by Envirocon (Envirocon 2004, revision forthcoming) contains a detailed discussion of the drawdown stages and associated RA work that will occur during those stages.

H.2.5.1 Reservoir Drawdown and Dam Removal

In summary, reservoir drawdown and dam removal are planned to occur in three stages. All stages are timed with the spring runoff period to minimize construction costs and sediment impacts.

Stage 1
The radial gate will be opened to allow the reservoir to drop about 10 feet in elevation. During this time, the CFR will remain in its present channel (CFR 2) while the bypass channel is being constructed between Duck Bridge and the confluence with the BFR. Stimson dam is also removed before or during this stage, which lasts about 1 year.

Stage 2
Water from the CFR will be diverted into the bypass channel. The Powerhouse turbine inlets are converted to low level outlets allowing an additional 5 to 6 feet of drawdown (15 to 16 feet total drawdown). During this time period, the spillway will be removed and the new CFR1 channel constructed through the spillway reach. This stage occurs over about 6-7 months between spring runoff periods.

Stage 3
Water will be diverted into the new CFR1 channel at the old spillway location allowing the reservoir to be drawn down an additional 12-13 feet for a total drawdown of approximately 27 ft to 29 ft. During the first part of stage 3, stage 3A, the powerhouse, radial gates and other structures associated with the dam will be removed. During the second part of this stage, stage 3B, sediment will be excavated from SAA I.

H.2.5.2 Coordination of Restoration Actions with Remedial Actions

Since the drawdown stages will ultimately determine the timing for restoration actions, the restoration actions have been grouped and discussed by drawdown stage. When developing the restoration timeline, the following items were identified as the most critical activities for restoration work to accomplish in order to coordinate with RA.

1. The State must coordinate with RA to ensure that reaches upstream and downstream of the RA project area are prepared to accommodate the bypass diversions.

2. Certain restoration actions may need to be accomplished prior to the pertinent drawdown stage in order to protect existing infrastructure. An example of this is the grade control and bridges protection structures on BFR1.

3. To minimize sedimentation and disturbance, the State should be prepared to take advantage of the required sediment control, river diversions and de-watering infrastructure required for RA. Such an example would be to take advantage of dry working conditions offered by coffer dams constructed during RA.

4. To reduce risk of damage and reduce the cost of restoration, the State must be prepared to work within a fixed time period to complete certain restoration actions following RA sediment removal.

H.2.5.3 Implementation Schedule

A proposed implementation schedule is presented in Table H-27. The schedule includes tasks related to restoration design, construction, revegetation and monitoring for the four project reaches. The implementation schedule has been integrated with the RA construction and reservoir drawdown stages as shown on the top line of the schedule. The proposed implementation schedule displays the approximate time frames for the drawdown stages and the subsequent restoration action associated with each stage. Following approval of the Envirocon SOW, a calendar will be incorporated into the implementation schedule

<u>Stage 1 Restoration Actions (Year 1 and 2)</u>
No restoration construction will take place during stage 1. Stage 1 will draw the reservoir down to a similar level as recent draw downs. During stage 1, one runoff event will occur. Cooperating parties will remove the Stimson Dam before runoff occurs.

Depending on the schedule, it may be necessary to collect supplemental design data identified in the peer review process. Phase 3 design should be completed at least six months prior to stage 2, and preferably one year before stage 2. At a minimum, floodplain profiles should be finalized. Grade control structures on CFR1 near the dam and the BFR bridge sites should be completed at least six months prior to stage 2. Minimal time will be available to organize materials, logistics and complete the permitting process. Phase 3 designs may be completed for CFR2 and CFR3 over a slightly longer time period, but at least one year before initiation of Stage 3B so that Envirocon can prepare a final grading plan for SAA I.
<u>Stage 2 Restoration Actions (Year 2 and 3)</u>

During Stage 2, the reservoir will be drawn down to the minimum pool elevation possible without removing the spillway and dam. The reservoir will be drawn down approximately 15 to 16 feet from full pool. Stage 2 will begin in the fall following the stage 1 runoff event, and continue through the following spring. Stage 2 actions must be completed before the next runoff season to protect the infrastructure constructed during stage 1. The duration of stage 2 will be about six to seven months. To take advantage of drawdown and the RA coffer dam installed upstream from Milltown Dam to divert water through the radial gate, several restoration construction activities will take place during this short time period. The grade control structures for CFR 1 channel will be completed along with channel construction from approximately 200 feet upstream of the dam to approximately 700 feet downstream of the dam during dry conditions. This construction will entail constructing two large rock weirs in the CFR1 along with a coffer dam downstream of the dam to separate the new floodplain from the active channel. Also during this time period, the side channel on the river left side downstream from the dam will be reshaped according the final plan.

Other restoration activities that must be completed during stage 2 are the rock weir grade control structures on BFR1. To protect the bridge piers, structures must be installed before stage 3 drawdown is initiated. After the structures are placed in CFR1 and BFR1, the coffer dam will be removed and the CFR will flow through the new CFR1 channel at the dam site.

Stage 3A Restoration Actions (Year 3)

Stage 3A begins before the second spring runoff and continues until the powerhouse, radial gate and associated structures are removed. One runoff event will occur during stage 3A, which will cause some scour upstream from the dam in CFR1 and the lower section of BFR1. Channel scour is planned and covered in detail in the Envirocon Scour reports. The resultant water levels will be approximately at the final proposed water surface elevations in the lower reaches of the project.

Immediately after the runoff event has concluded and water levels drop to low flow conditions, the water can be diverted into the left side channel of the CFR1 downstream from the dam. This will allow the CFR1 channel and floodplain downstream from the dam to be completed in dry conditions. Also during this time period, the BFR1 channel upstream from the bridges to the terminus of the reach may be completed.

If necessary, the construction of CFR1 downstream from the dam and BFR1 upstream from the bridges could be completed later in the planning process, in year 5 or 6. This delay may be necessary if designs, permits or other considerations preclude completing the work during year 3. However, the water quality impacts associated with delays could prolong the period of sedimentation.

Revegetation efforts will be completed in phases during and after construction. Any equipment based revegetation will closely follow the final construction of any segment of river. Hand based planting will occur following construction and will extend several years after construction.

Stage 3B and 3C Restoration Actions (Year 4 and 5)

While Envirocon is removing sediment from SAA1 (CFR2), restoration actions will focus on the upper CFR reaches. Ideally, the upper half of CFR3 will be completed in Year 3 and 4. This will concentrate all water into a single channel, which can be diverted in the northernmost existing channel. This diversion will allow the excavation and construction of the lower half of CFR3, which requires lowering the floodplain by up to seven feet. The timing for the upper half of CFR3 is not as critical as the lower half of CFR3, however, because the lower half will need to be closely tied to the final grading of CFR2 by Envirocon. There will be an excess of approximately 200,000 cubic yards of material generated from excavating the floodplain in this reach. The material will be used for general fill and growth medium in CFR2. There is an opportunity to stockpile this material, but the costs would increase each time the fill is moved. The lower half of CFR3 will be coordinated with the final grading of CFR2.

The floodplain elevation of the upper half of CFR3 will not be changed appreciably, so construction of this reach could wait until year 5. However, any delays in construction could increase risk of damage to downstream reaches due to runoff events or floods. Planning in advance for this risk would be necessary and could also increase costs.

As soon as the lower half of CFR3 and the final grading of the CFR2 channel and floodplain are complete, the structures can be installed. Finish work and revegetation will follow in CFR2. Water would be diverted into the new channels, and the bypass channel would be re-graded to

final elevations. Revegetation in CFR2 and CFR3 would begin upon completion of final grading and continue for one year.

During year 4 or 5 low flow periods, CFR1 and BFR1 between the dam and Interstate 90 will be completed. The Envirocon scour model predicts that the scour process will scour the channel to alluvium, near proposed bed elevations. However, additional channel shaping, pool excavation and structure placement will need to be completed. This work must be accomplished in wet conditions.

Restoration Activities following Stage 3 (Year 6-9)

As discussed previously, channel work not completed during stage 3 will be completed in year 6 or year 7. Reaches that may fall into this category are CFR1 downstream from the dam and BFR1 upstream from the bridges.

Table H-27: Restoration schedule for the CFR and BFR.

Restoration Action	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7
	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4	1 2 3 4
Phase 2 Data Collection	Stage 1	Stage 2	Stage 3	Stage 3B and 3C			
Supplemental Data Collection							
Finalize Conceptual Plan							
Phase 3 Final Design							
BFR1							
CFR1							
CFR2							
CFR3							
Phase 4 Implementation							
BFR1 Grade Control at Bridges							
CFR1 Grade Control at Dam							
CFR1 Left Side Channel							
Divert Water into Left Side Channel				OR			
CFR1 Main Channel and Floodplain				OR			
CFR1 Between Dam and Confluence							
BFR1 Between I 90 and Confluence							
BFR1 Between Bridges and Upstream Extent				OR			
CFR3 Upper Half				OR	OR		
Divert Water into North Existing Channel							
CFR3 Lower Half							
CFR2 Structures and Finish Work							
Divert Water into CFR2 and Regrade Bypass							

- **BFR1**
- **CFR1**
- **CFR2**
- **CFR3**

H.2.6 Summary

Analog, empirical, and analytical methods were employed to develop the draft restoration design for the CFR and BFR in the vicinity of Milltown reservoir. Data collection included a large scale effort that documented existing and reference river corridor conditions on CFR and BFR both in the restoration project area and in surrounding reaches. Reference data were used to develop dimensionless coefficients that were in turn used to calculate potential design dimensions for the four project reaches: CFR1, BFR1, CFR2 and CFR3.

Empirical methods were also used to evaluate potential channel conditions as well as to investigate the likely historical and potential channel planform for CFR. Empirical equation results suggested that based on valley and channel slope, bank materials, and vegetation condition, the historical CFR planform was most likely described as a meandering or straight channel. Empirical equations also predicted a meandering channel based on the draft channel design dimensions.

Analytical methods included modeling channel roughness, incipient particle motion, channel velocities, sediment transport, and channel scour potential. Modeling runs were conducted for the reference reaches to characterize the existing conditions. Draft design cross-section channel dimensions derived from both the analog and empirical methods were also modeled. The final draft design cross-section channel dimensions were developed from the modeling run results.

Channel and floodplain gradients were provided for the four reaches as well. Preliminary floodplain gradients were developed from field data and were designed to tie to existing vegetated floodplain features. Restoration project area constraints and criteria from the stable slope analysis were also used to develop the floodplain gradients. Channel habitat units were not included in the longitudinal profiles and will be further evaluated during the final design phase.

Channel planform geometry was developed from analog and empirical sources. Planform options vary by reach according to valley bottom width. Only one channel alignment option was evaluated for reaches with narrow valley bottoms, namely CFR1, BFR1, and CFR2. The more expansive CFR3 valley bottom allows more flexibility in designing the channel planform. Four potential options were developed for this reach with Alignment C being the preferred design planform. More details will be determined in the final design phase.